Fluvial Geomorphology Assessment of Grand Lake Stream, Maine

Prepared for

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EXECUTIVE SUMMARY

A fluvial geomorphology assessment was conducted on Grand Lake Stream in Washington County, ME to determine what factors are leading to channel instability and habitat degradation. Log drives on the stream for over 150 years were likely responsible for channel straightening, channel constrictions, and removal of boulders from the channel. These past activities continue to have an impact through the loss of pool habitat, erosion of high banks of glacial deposits, and excess deposition of fine sediments.

Three study reaches, reflecting the range of channel impacts, were surveyed in detail to identify restoration options that can restore natural stream processes and improve aquatic habitat. Reach 1, between the fish hatchery and Big Falls, is a naturally wide channel that experienced a loss of pool habitat when boulders were moved to the margin of the channel. The placement of paired boulder clusters in the stream represents the best option for restoring pool habitat without altering the natural appearance of the stream channel.

Reach 2, upstream of Little Falls, was straightened prior to 1917 and is now characterized by mid-channel bars forming where confined flow from upstream spreads out over a low floodplain and into multiple side channels. Diversion of flow around the mid-channel bars is associated with the erosion of a 30-foot high bank. Valley confinement upstream is partly the result of artificial constrictors built in the channel. The resulting excess sediment delivered downstream to Reach 2, a naturally unconfined area, means channel instabilities persist to this day. Consequently, restoring bank stability and aquatic habitat will be difficult unless upstream sediment delivery is reduced.

Reach 3, downstream of Gould Landing to the confluence with Big Lake, is a natural area of deposition where flow to side channels and a marsh were blocked in order to move logs further into the lake and to maintain sufficient water depths for boating. The constructed channel constrictors have since fallen into disrepair and the return of more natural flow conditions has led to the formation of a delta at the upstream end of the reach and infilling of the channel with mud downstream. Maintaining water depths either through dredging or reconstruction of the channel constrictors will require periodic maintenance as these measures would work against natural stream equilibrium. Of all the restoration options considered for the three reaches, the addition of boulder clusters in Reach 1 has the greatest potential to improve aquatic habitat, restore natural stream conditions, and garner favorable public support.

1.0 INTRODUCTION

This report describes a fluvial geomorphology assessment completed by Field Geology Services on Grand Lake Stream in Washington County, Maine (Figures 1 and 2). Grand Lake Stream is only 3.4 miles long and connects West Grand Lake at the upstream end with Big Lake downstream. The watershed area of Grand Lake Stream is 227 mi^2 above the USGS stream gauge in the Town of Grand Lake Stream. Grand Lake Stream and adjoining lakes are popular locations for salmon and bass fishing but are also home to the diadromous American eel (*Anguilla rostrata*). Several decades of log drives and other human land uses in the stream and surrounding watershed have left parts of the channel overwidened (Figure 3), some of the river banks unstable (Figure 4), and formerly deep pools filled in with sediment (Jeff McEvoy, personal communication, 2004). The effect of these physical changes to the stream's morphology has caused a significant decrease in the velocity and depth diversity along the stream, an important component of American eel habitat (Wiley et al., 2004). The fluvial geomorphology assessment was conducted to better understand the causes for these channel instabilities and to identify areas where stream restoration projects could improve physical habitat conditions for American eel and other fish species inhabiting the stream. Restoration options that address the causes for channel instability have a better chance of long term success and can potentially improve stability beyond the project site.

The fluvial geomorphology assessment had three major objectives: 1) identify sediment sources and other causes for channel instability; 2) locate areas where diadromous eel habitat is significantly degraded; and 3) produce conceptual restoration design drawings for three high priority sites that address the causes for channel instability while improving habitat for diadromous fish species. Five areas of study were undertaken in order to meet these objectives: 1) investigation of historical information including historical maps, archival documents, and peak discharge records; 2) mapping of channel features; 3) topographic surveying; 4) determination of substrate particle size; and 5) analysis of restoration design options. The results of each area of study are described separately below and provide the basis for a discussion of channel instabilities, habitat degradation, and potential restoration options.

2.0 HISTORICAL INFORMATION

2.1 Historical Maps

Historical topographic maps surveyed in 1941 were compared with the most current topographic maps and aerial photographs to identify changes in channel position and other features on Grand Lake stream during the past 65 years (Appendix 1). No significant channel changes are observable on the maps, but the channel does appear wider with a sharper bend at the downstream end of the fish hatchery in the Town of Grand Lake Stream (Figure 5 – Point A). Additionally, mid-channel bars currently found 1,500 feet upstream of Little Falls (Figure 5) are not present on the 1941 map. However, these minor changes might be the result of greater resolution in the later maps rather than representing actual changes. The only other noteworthy difference between the historical and current maps is that Gardner Brook currently flows directly into Big Lake but in 1941 flowed into Grand Lake Stream near Gould Landing (Figure 5 – Point B).

An analysis of the current topographic map and aerial photograph reveal former channel positions that were abandoned prior to1941 but whose traces are still visible. The most significant of these are described below. Long before 1941, perhaps thousands of years ago, Grand Lake Stream flowed into the lower end of Gardner Brook through the low divide at Gould Landing (Figure 5 – Point C). A natural distributary network of branching channels on Grand Lake Stream downstream of Gould Landing formed where the stream enters Big Lake. However, prior to 1941 the construction of a low long linear structure parallel to the stream confined the channel along its right bank (looking downstream)(Figure 5 – Point D). This constrictor was likely built to maintain flow velocities into the lake for log drives and to retain channel depths for boats headed to Gould Landing. A meander downstream of Little Falls occupies only a small portion of a former, much broader, meander as evidenced by the presence of wetlands on the outside margin of the current channel (Figure 5 – Point E). Upstream of Little Falls, a meander of the stream was abandoned (Figure 5 – Point F) when the channel was straightened (Figure 5 – Point G), most likely the result of human activity associated with log drives. Further upstream, the channel adjacent to the fish hatchery was also artificially straightened and constricted as the wide floodplain available for natural meandering is no longer occupied by the channel (Figure 5 – Point H). Between the fish hatchery and Big Falls (Figure 2) the channel is also straight, but this may simply be the result of natural confinement rather than artificial straightening, because only a very narrow floodplain exists at this locality.

2.2 Archival Documents

Numerous historical ground photographs and other archival documents were analyzed at the Grand Lake Stream Historical Society in the Town of Grand Lake Stream to identify changes that occurred on the stream prior to the oldest topographic map. A dam was first built across the upstream end of Grand Lake Stream in 1810 about 165 feet downstream of the current dam (Atkinson, no date). The dam was constructed initially to assist with log drives (Figure 6), which continued to occur on the stream through the 1970’s. A large tannery operation was constructed on the banks of Grand Lake Stream beginning in 1870 at the current location of the fish hatchery. A canal connecting West Grand Lake to the tannery was constructed at the same time and is still used for the fish hatchery operations (Figure 5 – Point I; Figure 7). While the tannery closed down in 1883, the hatchery was opened at the site by 1906 and continues to the present day. The hatchery occupies a portion of the floodplain, so the stream channel may have flowed across this area prior to the construction of the tannery in 1870.

A ground photograph upstream of Little Falls in 1917 shows the channel in its current position (Figure 8), indicating that artificial straightening and abandonment of the meander occurred prior to this time.

2.3 Peak Discharge Records

A record of peak discharges for the stream gauge on Grand Lake Stream at Grand Lake Stream, Maine (USGS gauge 01019000) is available at: http://nwis.waterdata.usgs.gov/me/nwis/peak/?site_no=01019000. The nearly 80-year gauge record has been affected by flow regulation since its inception with a record peak flow of only 2,870 ft^3/s recorded on April 25, 1983 (Figure 9). In comparison, the record peak flow on the unregulated Narraguagus River at Cherryfield, Maine with the same drainage area exceeded 10,000 ft^3/s (see http://nwis.waterdata.usgs.gov/me/nwis/peak/?site_no=01022500). However, the record peak flow on the unregulated East Machias River in East Machias, Maine, with a slightly larger drainage area, is less than 4,000 ft^3/s, indicating that the presence of large lakes in a watershed can naturally attenuate peak flows (see http://nwis.waterdata.usgs.gov/me/nwis/peak/?site_no=01022000). Consequently, West Grand Lake may exert just as strong a control on peak flows as the dam itself. A large spring flow on Grand Lake Stream in 1873 nearly washed out the dam (Atkinson, no date), but the lack of gauge data precludes a comparison to the gauged record beginning in 1929.

3.0 MAPPING OF CHANNEL FEATURES

A number of channel features were mapped continuously along the entire 3.4 mile length of Grand Lake Stream and entered into a GIS database (Appendix 2) with the statistical results summarized in Table 1. The features mapped were: bank stability (e.g., eroding, stable, and riprapped banks), bank composition (e.g., floodplain sediment, glacial deposits, and bedrock), substrate particle size (e.g., cobbles, gravel, or sand on channel bed), depositional features (e.g., mid-channel bars, point bars), riparian buffer width (width of trees growing along beside the river bank), and human activities in the channel (e.g., dams, bridges, constrictors). The channel features were precisely mapped onto vellum sheets overlaying aerial photographs while walking the stream's length. The mapped features were then hand digitized into an ArcView GIS project.

Very little erosion is observed along Grand Lake Stream (< 3 percent) with some found immediately downstream of the dam (Figure 10 and Appendix 2). Additional erosion is found between Big Falls and Little Falls with a particularly high eroding bank located 950 feet upstream of Little Falls (Figure 4). While some residents further downstream believe this bank is a source of considerable sediment, a resident with a view of the bank indicates that the bank has changed very little in over 20 years. Lichen and tree growth on the sandy bank and the absence of vertical faces is consistent with the lack of significant erosion. However, the absence of mature trees on the bank and recently fallen trees just downstream suggest the bank is unstable and susceptible to erosion. A mid-channel bar situated adjacent to the high eroding bank is diverting a portion of the flow directly into the bank, perhaps leading to the erosion. Whatever excess sediment is eroded from this bank is unlikely to be transported much further than immediately downstream of Little Falls where the valley becomes much wider and extensive deposition is observed.

Mid-channel bars are found along 7 percent of the length of Grand Lake Stream with most of these concentrated between Big Falls and Little Falls (Table 1 and Appendix 2). These gravel bars have formed downstream of where the channel is confined between high nonalluvial slopes of glacial deposits. The loss of valley confinement leads to deposition as flow spreads out into numerous side channels and flow velocities reduced. Several flow deflectors and constrictors (i.e., weirs or crib walls) have been built along the stream, including just upstream of these mid-channel bars, where natural valley confinement is lost (Appendix 2). The construction of these constrictors was likely associated with log drives in an effort to block flow from entering side channels, maintain flow velocities, and improve the transport of logs downstream. Since the end of log drives, many constrictors have fallen into disrepair, allowing flow to more regularly access side channels (Figure 11).

High banks of nonalluvial glacial deposits are found along 26 percent of the stream's length with another 10 percent of the bank length composed of bedrock (Table 1). The nonalluvial banks are always more than 5 feet high but in many places exceed 30 feet in height. In contrast, alluvial banks, where the channel flows on a floodplain, are less than 5 feet high. Although the nonalluvial banks are stable in most places, the considerable length of channel flowing against these high banks means that a tremendous source of sediment can be made available to the stream during large storm events. Although no single sediment source is apparent, the presence of multiple mid-channel bars downstream of where the stream encounters the greatest unbroken length of nonalluvial banks (i.e., downstream of Big Falls) suggests some sediment is generated from these high banks. A wide riparian buffer along most of the stream (> 200 feet in width along 79 percent of the channel)(Table 1), especially between Big Falls and Little Falls (Appendix 2), greatly reduces the amount of sediment potentially entering the stream. If the high nonalluvial banks were to become unstable, due to land clearance or other factors, the excessive amount of sediment that could be introduced from this external source would lead to dramatic stream channel adjustments. The response would continue until either sediment production was reduced or the channel response progressed sufficiently to enable the stream to transport the greater sediment load – a process that would likely take several decades. Consequently, future management around Grand Lake Stream should ensure the stability of the high nonalluvial banks along the channel.

4.0 TOPOGRAPHIC SURVEYING

Topographic surveying of channel morphology can identify channel instabilities that might lead to degraded aquatic habitat. Surveying of three study reaches along Grand Lake Stream was conducted to characterize channel morphology, identify channel alterations and adjustments resulting from human activity, and to design conceptual restoration options for improving channel stability and aquatic habitat (Figure 2). The three reaches chosen reflect a range of human altered conditions present on the stream. Although the original project proposal envisioned surveying one reference site, no suitable reference conditions were found that could be used for comparing undisturbed conditions with the other reaches. Consequently, a third study reach was investigated instead.

Surveying of the three reaches was conducted using a Sokkia Set 5 Electronic Total Station. A longitudinal profile and multiple cross sections were measured at each site (Appendix 3). The longitudinal profiles measured the thalweg (i.e., deepest part of the channel) and water surface elevation from the upstream to downstream end of the channel, providing information on channel gradient, bed features (e.g., pool depths, pool spacing), and planform (e.g., sinuosity, meander wavelength)(Table 2). The channel cross sections measured the channel dimensions in each reach including bankfull depth and width (Table 2). Measurements were also made along the top and bottom of the bank to assist in the development of site maps used in the development of conceptual restoration design options (see Section 6.0 below).

A description of each reach with a further discussion of the survey results is provided below:

4.1 Reach 1: Fish Hatchery to Big Falls

Reach 1 extends from the downstream end of the fish hatchery to Big Falls (Figures 2 and 12). The reach is straight and may have been artificially straightened, although this remains uncertain given that the narrow floodplain would limit natural sinuosity. The high width:depth ratio (> 30.0) of the channel is consistent with a channel response to artificial straightening, but may also reflect the inability of the channel to erode through the coarse channel substrate inherited from the surrounding glacial deposits (see Section 5.0 below). Several boulders are found along the banks with only a few located in the center of the channel, suggesting boulders were removed to ease the floating of logs downstream. Where boulders are present in the stream, deep pools have formed around them, sometimes both upstream and downstream (Figure 13). Pools are otherwise widely spaced and shallow, although, given the wide channel, pools are closely spaced at every 1.3 bankfull widths compared to an expected spacing of 5 bankfull widths (Table 2; Rosgen, 1996).

4.2 Reach 2: Upstream of Little Falls

Reach 2 is located upstream of Little Falls and extends from multiple mid-channel bars downstream to a high eroding bank of glacial outwash sediments (Figures 2, 4, and 14). The reach was artificially straightened prior to 1917 (Figure 8) as evidenced by a wide low floodplain along the left bank with an abandoned meander; this old meander is likely the former position of the channel before straightening. Flow frequently overtops the left bank in many areas with fresh sand deposits and organic debris observed in the young floodplain forest. The lack of flow confinement in this reach contrasts with immediately upstream where the channel is confined by high nonalluvial banks on both sides of the channel. The upstream reach is further confined by artificial constrictors most likely constructed for log drives. Consequently, excess sediment is delivered downstream to Reach 2 where cobble and gravel deposition is occurring, because other constrictors that previously blocked side channels have fallen into disrepair. Multiple mid-channel bars have been deposited as a result and a high width:depth ratio (>30.0) characterizes channel morphology. Pools are widely spaced and shallow, although, given the wide channel, pools are spaced every 2.9 bankfull widths (Table 2). In addition, the artificial straightening may have led to channel widening and loss of bed complexity (i.e., loss of pools) as the channel responded to the increased slope caused by straightening.

4.3 Reach 3: Downstream of Gould Landing

Reach 2 extends from Gould Landing, just downstream from the ledge controlled rapids, to the confluence with Big Lake (Figures 2 and 15). Given the length of the reach, surveying was subdivided into an upstream and downstream section (Appendix 3). A long narrow earthen constrictor defines the right bank of the channel for most of the reach (Figure 5 – Point D). The top of the constrictor is very low (Appendix 3), barely extending above the water surface, but does separate the channel from a marshy area on the opposite side of the constrictor. The constrictor is currently breached at the upstream end with minor amounts of flow moving into the marsh from the channel even at low flow conditions. The structure may have been higher in the past and was possibly constructed as log cribbing with rocks filling the center, as observed on another structure further upstream on the left bank (Figure 11). However, the internal structure of the long constrictor is currently obscured by mud deposits and shrub growth. The shorter constrictor on the left bank previously blocked flow from entering a side channel, but is now in such significant disrepair that flow crosses over the structure even at lower discharges (Figure 11).

The structures on both banks were built prior to 1941 (Appendix 1) to extend log drives further out into the lake and to maintain water depths for boats trying to reach Gould Landing. While the constrictors may have been repaired after 1941, they have fallen into greater disrepair since the end of log drives in the 1970's. Residents living along the left bank report a continuing decline in water depths that they ascribe to deposition of fine sediments in the channel. A thick deposit of very soft mud is present along the right bank of the channel.

As the channel leaves the rock ledges at Gould Landing the flow begins to spread out into a wide embayment of Big Lake. Although flow is still well defined and confined by the artificial constrictors described above, a delta of sand and gravel is building out into the channel as flow escapes into the side channel on the left bank and marsh on the right. The water surface slope is very low (<0.0001) as the channel enters the lake. Bed topography is also subdued with a very wide pool spacing (> 800 feet); the greatest "pool" depth is found at the base of the delta front (Table 2 and Appendix 3). The width:depth ratio of the channel is less than 20.0 immediately downstream of the rock rapids at Gould Landing but quickly becomes greater than 60.0 as flow spreads out into the side channel on the left bank; the currently dilapidated constrictor, when functioning, would have maintained a width:depth ratio of less than 30.0 by blocking access to the side channel (Figure 16). Despite the constrictor on the right bank further downstream, the width:depth ratio is over 45.0, reflecting both the infilling of the channel with fine sediment and expansion of flow as the stream enters Big Lake.

5.0 SUBSTRATE PARTICLE SIZE

The substrate particle size at each study reach was determined using the pebble count method described in Rosgen (1996) where the intermediate axis diameter of 100 particles is measured. The results of the pebble count measurements are displayed as cumulative histograms in Appendix 3. Particle size was reasonably uniform in Reach 1 and Reach 2, so only one pebble count was conducted in each reach. Two pebble counts were measured in Reach 3 because of the rapid decrease in grain size associated with deposition of the delta as the flow spreads out into the wide embayment of Big Lake. Downstream of the delta front the substrate is comprised of sand and finer sediments, so a third pebble count was not conducted.

The particle size information was used to determine if bankfull flows within each reach are sufficient to mobilize the channel substrate. Shields' equation is used to determine the critical shear stress necessary to mobilize particles of a certain size (Table 3; Shields, 1936). Sediment is mobilized in the channel when the shear stress in the channel exceeds the critical shear stress; bankfull shear stresses for each reach were calculated from the slope and bankfull dimensions measured during surveying (Table 3 and Appendix 3). Bankfull shear stresses in Reach 1 (Figure 2) are less than the critical shear stress needed to mobilize the median particle size (D50), suggesting that at least the coarsest bouldery substrate is inherited from glacial deposits exposed in the nonalluvial banks lining the channel. Given the narrow floodplain and confined nature of the channel, shear stresses during large floods may greatly exceed bankfull shear stresses. Consequently, substrate in Reach 1 may be periodically mobilized. Finer sediment would be more frequently transported, leading to channel armoring where only the coarsest less mobile sediment remains on the channel bed. The coarse substrate may have led to the high width:depth ratio of the channel (Table 2). If the channel cannot mobilize the bed sediments, erosion of the finer bank sediments will preferentially occur, leading to a widening of the channel.

Bankfull shear stresses in Reach 2 exceed the critical shear stress needed to mobilize the median particle size (D50). Substrate on gravel bed streams is typically mobilized at or near bankfull conditions as appears to occur in Reach 2 where bankfull shear stresses are just slightly above the critical shear stress (Table 3). Coarser sediment would not be easily transported through the reach, as the unconfined nature of Reach 2 would limit the amount of shear stress that would develop in the channel. As flows spread out on the floodplain, water depths, and depth-dependent shear stresses, would remain essentially the same in the channel even with large increases in discharge. Consequently, coarse particles, more easily mobilized in the confined reaches upstream, would be deposited in Reach 2 as shear stresses decline, leading to the formation of the mid-channel bars observed in the reach.

Bankfull shear stresses in Reach 3 are far below the critical shear stress needed to mobilize the median particle size (D50)(Table 3). The decreasing slope as the stream enters Big Lake results in a rapid decline in shear stress. The developing delta at the upstream end of the reach reflects the stream's rapid loss in competence to move larger particles. Downstream of the delta front only sand and finer particles are observed, reflecting the stream's inability to transport gravel or coarser sediment on the extremely low slopes.

Despite the coarse nature of sediments in Reaches 1 and 2, both reaches have greater than or near 10 percent sand as part of the channel substrate (Table 3). Fine sediment causes embeddedness which can cause a decline in habitat quality. Many macroinvertebrates require rocky substrates to survive, so sand covering the rock surfaces represents lost habitat. Additionally, several fish species require clean gravel for spawning and incubation of eggs. Survival of the eggs declines rapidly if fine sediment fills the interstitial spaces between the gravel, because water flow through the gravel is impeded and oxygenation of the eggs compromised. While the fine sediment levels in Reaches 1 and 2 are probably too low to cause significant problems, the levels are probably near a threshold point where minor additional increases in fine sediment may cause significant declines in habitat quality.

6.0 RESTORATION DESIGN OPTIONS

Five restoration options, including doing nothing, were considered for improving channel stability and aquatic habitat in each of the three study reaches. Conceptual plan view designs and cross sections were developed for each option with a list of pros and cons also provided (Appendix 4). A brief discussion of each reach and the selection of a preferred restoration option are provided below:

6.1 Reach 1: Fish Hatchery to Big Falls

The five restoration options considered for Reach 1 were: 1) do nothing; 2) place woody debris on the banks; 3) excavate pools; 4) construct rock weirs; and 5) place boulder clusters in the channel (Appendix 4). Reach 1 is likely wide and shallow as a consequence of natural confinement and a coarse substrate inherited from surrounding glacial deposits. The removal of boulders from the stream for log drives has likely resulted in the loss of pools and pool depth, a condition that has worsened in recent years according to local residents. The continuing loss in the number and quality of pools may reflect a long lag time in response to the removal of boulders from the stream or may be the result of some other unidentified factors. Taking no action will unlikely result in pool formation over time as the pool forming elements (i.e., boulders) have been largely removed from the channel.

The placement of woody debris on the banks will likely increase cover habitat but will not improve pool habitat. Excavating pools in the channel will provide pools for a short time period. However, by disturbing the coarse armor on the channel bottom, fine sediment underneath may be mobilized that could ultimately lead to infilling of the pools after one or two sediment mobilizing stream flow events (i.e., 5-10 years). The construction of rock weirs or shorter deflectors across the channel would be designed to divert flow towards the center of the channel. While the focusing of flow will increase the flow's ability to scour the channel bed, the coarse armor layer may prevent the formation of pools unless the surface armor layer is disturbed or pools artificially excavated immediately downstream of the weirs. To be effective, the rock weirs would have to be constructed all of the way across the wide stream and, therefore, multiple weirs in the reach would be expensive to build and cause significant disturbance in the stream. Assuming a pool spacing of approximately three times the bankfull width of the channel, a typical spacing in step-pool systems (Rosgen, 1996), a total of four weirs would fit between the hatchery and Big Falls. Natural rock weirs, or steps, typically form where the stream's flow is competent enough to self-organize the cobbles and boulders in a linear fashion across the stream, a reflection of the stream's attempts to dissipate excess energy by creating roughness elements in the channel. In Reach 1, the analysis of substrate particle size (see Section 5.0 above) indicates that the stream is not capable of moving the largest boulders. Therefore, rock steps were probably not historically a component of Grand Lake Stream in this locality and the construction of weirs would look unnatural.

Boulder clusters placed in the stream could help sustain artificially excavated pools for longer time periods. Flow passing around the boulders or squeezing between paired boulders would generate sufficient scouring force to maintain the pools. Some of the best pool habitat currently present in the reach is associated with boulders (Figure 13). Simply placing boulders in the stream, however, may not lead to pool development as the armored channel bed may resist the additional scouring force. The boulder placements will have a greater chance of success if done in concert with the excavation of pools, or by disturbing the surface armor layer, immediately downstream. Although some infilling might be expected if the excavated pools are too large, some pool depth should be sustained. The creation of boulder clusters would most closely replicate stream conditions prior to log drives. The reuse of boulders moved to the channel margins would create a more natural look to the channel than if recently blasted rocks from a quarry were used.

Boulders and boulder pairs could be randomly scattered in the channel, but a downstream spacing of three times the bankfull width of the channel could be used to provide some guidance on the total number of boulder clusters needed. Additionally, no more than a third of the bankfull width should be occupied by a series of boulder clusters placed laterally across the stream in any 550-foot length of stream (i.e., 3x bankfull width) in order to avoid diverting significant amounts of flow into the channel banks. Assuming the use of boulders five feet in diameter, a total of six boulder pairs could fit within a 550-foot section of stream for a total of 24 randomly placed boulder pairs, or 48 boulders, in the approximately 2000-foot reach between the fish hatchery and Big Falls. Boulder pairs are likely to be more effective than single boulders as water passing through the paired boulders would be constricted, move faster, and, therefore, more effectively scour and maintain pools. However, a mix of paired and single boulders would likely be more natural looking and aesthetically pleasing. To improve habitat further, logs could be cabled to the rocks and allowed to float over the pools for additional cover. Although excavators would likely be needed to move and place the boulders, the use of long extensions on the excavators may minimize the impact of the excavators on the stream bed. The placement of boulder clusters in conjunction with the excavation of pools is the favored restoration option in Reach 1 because of the potential to sustain more, higher quality pools while returning the stream to conditions that existed prior to log drives.

6.2 Reach 2: Upstream of Little Falls

The five restoration options considered for Reach 2 were: 1) do nothing; 2) riprap the high eroding bank; 3) construct rock weirs; 4) divert flow into the abandoned meander; and 5) anchor woody debris to the base of the eroding bank (Appendix 4). Reach 2 was artificially straightened prior to 1917 and the subsequent widening of the stream plus constriction of flow further upstream between nonalluvial slopes and artificial constrictors has led to the loss of pools and deposition of multiple mid-channel bars. Flow around one mid-channel bar is diverting flow into a high eroding bank and may be sustaining bank instability (Figures 4 and 14). Doing nothing at the site will likely lead to further deposition in the channel, bank instability, and continued overflow into the abandoned meander. Eventually, flow could be diverted back into the old meander or create a new channel across the low floodplain along the left bank. Riprap (i.e., large stone) on the high eroding bank would create a hard point on the bank that would lead to preferential scour. Ultimately, the stone placed on the eroding slope could be undermined if not originally constructed below the channel bed. Even if constructed correctly, the cessation of erosion on the high bank could lead to the destabilization and erosion of adjacent, currently stable, slopes. The potential negative impacts outweigh the temporary stabilization of a slope that evidence suggests is not rapidly eroding or a significant source of sediment to the stream.

The construction of rock weirs would be designed to divert flow away from the bank and to scour pools at the center of the channel. Weirs are built to mimic natural steps that form in steep streams where excess stream energy is available to transport sediment through the reach. Therefore, weirs in Reach 2 would likely be counterproductive as the added roughness created by the step would encourage deposition and, at the end of a flood flow, fill in any pool scoured earlier in the flood. Further deposition in the channel could reorient flows back towards the bank and exacerbate the erosion problem the weirs are intended to fix. Reducing sediment loads from upstream would increase the likelihood that weirs or other restoration approaches would succeed, but the consideration of restoration options upstream was beyond the scope of the current assessment.

Diverting flow into the old abandoned meander with an engineered log jam in the current channel would return the stream to a pre-straightened condition while moving flow away from the high eroding bank. The channel substrate would likely be better segregated because of the greater flow velocity variations across the channel – faster flowing water and coarse sediment on the outside of the meander and slower velocities and finer sediment on the inside of the bend. The greater flow variations across the channel would also lead to greater bed complexity with the plane bed morphology in the currently straightened channel replaced by pool-riffle morphology in the meander bend. While habitat within the reach could be potentially restored by diverting flow into the old meander, a number of unintended consequences could result from pursuing this restoration option. The abandoned meander is currently a marshy area supporting a number of plant and animal species that would likely be displaced with a change in flow regime. The stream has been adjusting to the straightened channel configuration for several decades and a return to the preexisting conditions would also cause channel adjustments beyond the project reach. While Little Falls downstream would attenuate downstream impacts, upstream changes would be difficult to fully anticipate. In addition to technical concerns, the cost of blocking flow from the current channel and restoring it to the abandoned meander would be prohibitive.

Anchoring logs and root wads to the base of the high eroding bank would deflect water away from the high bank while providing cover. The restoration work would mimic natural debris jams that form along rivers and streams with high wood loads. While such jams are not currently abundant on Grand Lake Stream, they may have existed before the intense land clearing that accompanied settlement of the region. As the current forests continue to mature and older trees die off over the next several decades, natural log jams may form again along the banks of Grand Lake Stream. Unlike riprap, flow into the bank would be baffled by log jams, so downstream impacts or intense scour at the base of the bank are less likely. To avoid destabilizing the bank, the logs and root wads should not be inserted into the bank but rather cabled to rock on the bank or buried in the bed of the channel. Installing the logs and root wads might require the use of excavators, which would cause some disturbance in the channel. As a result, doing nothing is the preferred option for Reach 2, because of the potential impacts associated with the other options. However, anchoring logs and root wads to the base of the high eroding bank, as the least disruptive and most natural of the restoration options, should be considered further if rapid recession of the high bank is observed and the sediment generated from such erosion becomes a more serious concern.

6.3 Reach 3: Downstream of Gould Landing

The five restoration options considered for Reach 3 were: 1) do nothing; 2) straighten the channel; 3) dredge the channel; 4) reconstruct the channel constrictors; and 5) partially dismantle the long channel constrictor (Appendix 4). During the era of log drives, channel constrictors were built to narrow the channel and maintain flow velocities further out into the lake. As these structures have fallen into disrepair, a delta has formed at the upstream end of the reach and mud deposition has occurred further downstream. Reducing erosion of the high bank upstream of Little Falls will do very little to reduce the formation of the delta as any excess sediment from this bank is likely stored in the broad meanders and marshy area downstream of Little Falls. Since the growth of the delta represents a return to natural conditions that predominated in this broad embayment of Big Lake before the onset of log drives, doing nothing at the site will likely lead to further sedimentation, shallower water depths, and continued frustration for landowners attempting to maintain a channel for boating. The delta at the upstream end of the reach is forming in a big bend of the channel. Straightening the channel by blocking the main channel with an engineered log jam would divert flow into a side channel and increase the slope of the channel. Shear stress in the channel would increase only slightly as the current sinuosity is low (Table 2), so the current depositional regime would likely persist. The side channel to be activated in this restoration option was previously cut off from the channel by a constrictor that is currently in disrepair (Figure 11).

Dredging the channel would increase water depths in the channel temporarily, but the reduction in slope accompanying the removal of sediment will encourage further deposition. Consequently, this option alone is not sustainable and dredging would need to be redone periodically in order to maintain water depths. Water depths might be sustainable if dredging was done in conjunction with the reconstruction of the channel constrictors. The increased flow velocities resulting from flow constriction may be sufficient to transport sediment through the reach and out further into the lake, but the increased sediment delivery to the lake would have unknown environmental consequences. Both dredging and reconstruction of the constrictors would require considerable mechanized disturbance in the channel and would be prohibitively expensive.

Dismantling portions of the long constrictor on the right bank of the channel (Figure 5 – Point D) would restore additional flow to the marshy area behind. More regular flow in the marsh would likely enhance the marsh ecology and provide habitat benefits. However, the loss of flow from the channel would promote further deposition and result in an even shallower channel. The preferred option at the site depends on priorities of the landowners and other interested parties. If the priority is maintaining water depths in the channel for boating, then reconstruction of the constrictors with dredging is the best option despite the environmental consequences. Reconstruction also presents an opportunity to preserve historical cultural resources and provide a living reminder of the importance of logging and log drives to early settlers of the region. However, if the creation and restoration of a natural ecosystem is the priority, then partial deconstruction of the constrictor is the best option as this most closely mimics what will naturally occur over time and what would have developed if the constrictors had never been built.

7.0 CONCLUSIONS

Over 150 years of log drives on Grand Lake Stream altered stream channel morphology and led to stream channel adjustments that continue to this day. The loss of pool habitat was the likely consequence of removing boulders from the center of the channel between the fish hatchery and Big Falls. Additional pool habitat was lost upstream of Little Falls in response to channel straightening and excess sediment deposition from naturally and artificially constricted portions of the channel upstream.

Several places along the stream were artificially constricted by constrictors built with log cribbing filled with rock (Figure 11). As the constrictors fall into disrepair, flow to previously blocked side channels has resumed, leading to the loss of stream energy and deposition of sediment entrained in the water. This deposition is causing the formation of mid-channel bars and deltas that are diverting water into unstable banks (Figure 4) and infilling already shallow channels. The loss of channel depth due to flow expansion through old constrictors downstream of Gould Landing is particularly troublesome for landowners trying to access the channel with boats. Restoration of the constrictors may sustain channel depths but runs counter to natural stream processes in low gradient unconfined stream reaches. Consequently, periodic maintenance would be required to maintain sufficient channel depth. Greater improvements to channel stability and aquatic habitat can be expected where restoration mimics natural stream processes and evolution. As such, the addition of boulder clusters between the fish hatchery and Big Falls has the greatest chance of successfully restoring and sustaining natural stream channel conditions and pool habitat.

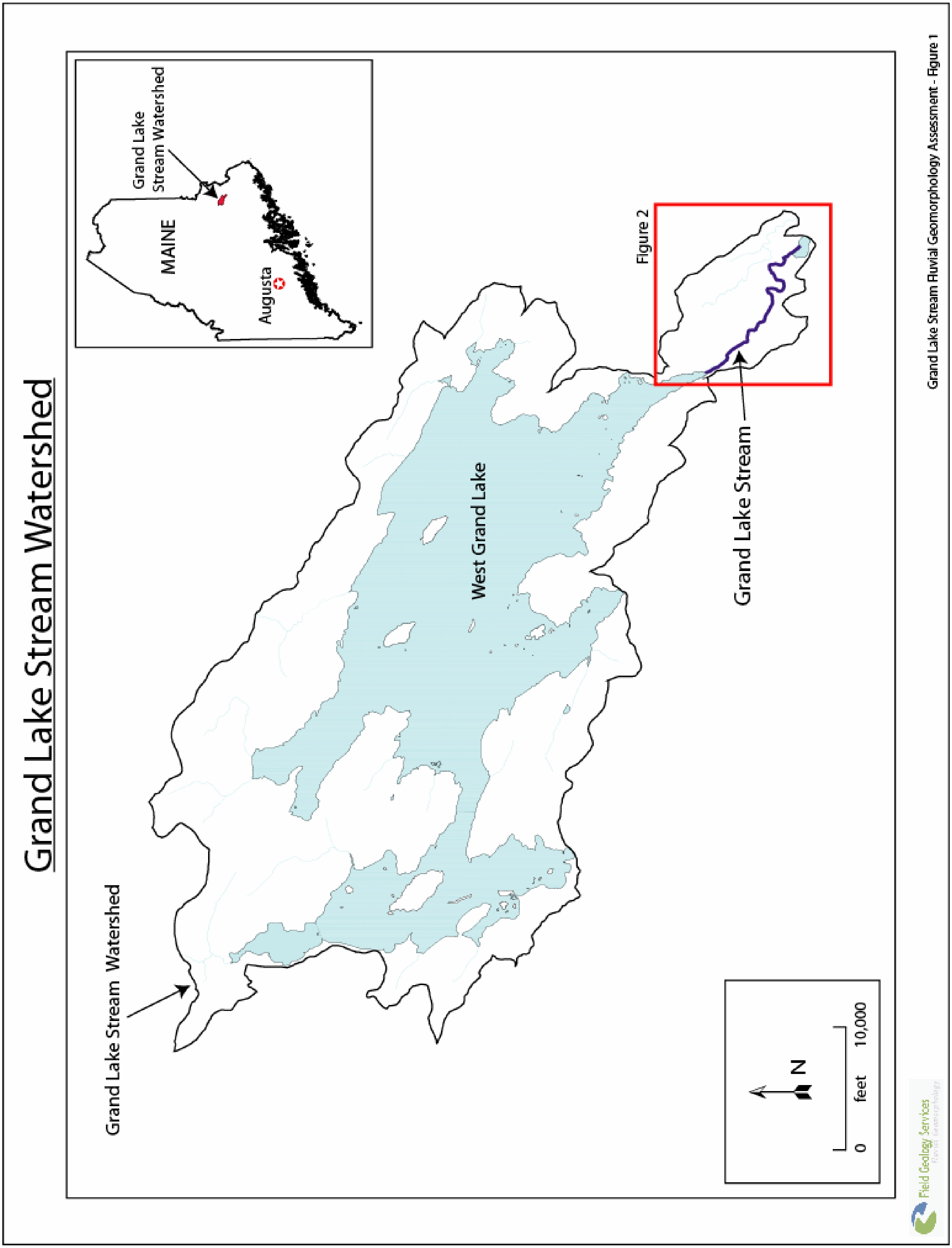
8.0 REFERENCES

Atkinson, M., no date, Hinckley Township or Grand Lake Stream Plantation: Grand Lake Stream Historical Society: Grand Lake Stream, ME, 122p.

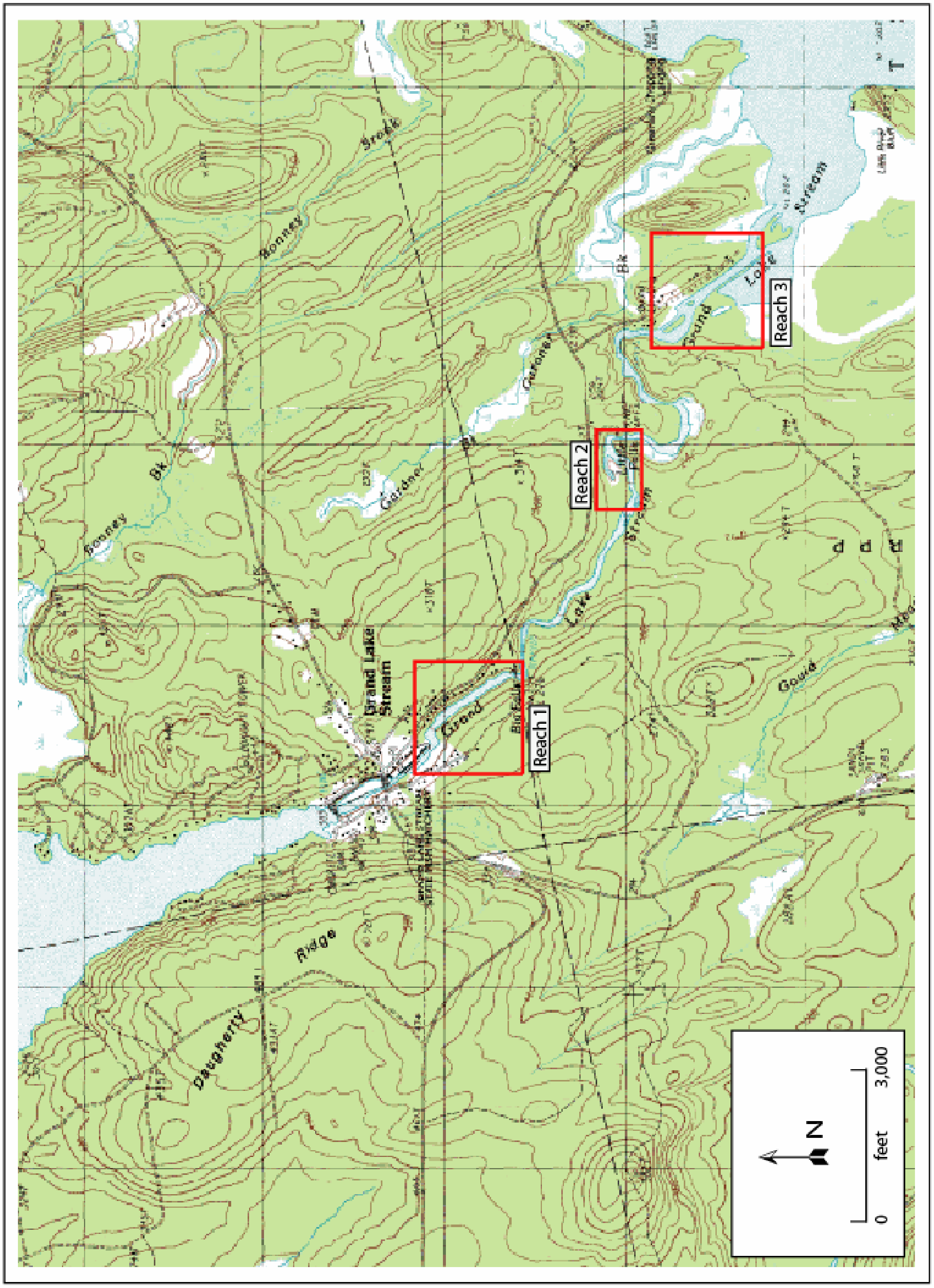
Rosgen, D.L., 1996, Applied River Morphology: Wildland Hydrology: Pagosa Springs, CO.

Shields, A., 1936, Anwendung der Ähnlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung: Mitteilung der Preussischen Versuchsanstalt für Wasserbau und Schiffsbau: Berlin, v. 26, 26 p.

Wiley, D.J., Morgan, R.P., Hilderbrand, R.H., Raesly, R.L., and Shumway, D.L., 2004, Relations between physical habitat and American eel abundance in five river basins in Maryland: Transactions of the American Fisheries Society, v. 133, p. 515-526.


Grand Lake Stream Watershed
Grand Lake Stream Watershed
Grand Lake Stream Watershed
MAINE
Augusta
West Grand Lake
Grand Lake Stream
Figure 2
N
0
feet
10,000
Field Geology Services
Grand Lake Stream Fluvial Geomorphology Assessment - Figure 1

Grand Lake Stream Study Area



Grand Lake Stream Fluvial Geomorphology Assessment - Figure 2

Field Geology Services

Overwidened Stream Channel

Note: Looking downstream near fish hatchery

Field Geology Services
Fluvial Geomorphology

Grand Lake Stream Fluvial Geomorphology Assessment – Figure 3

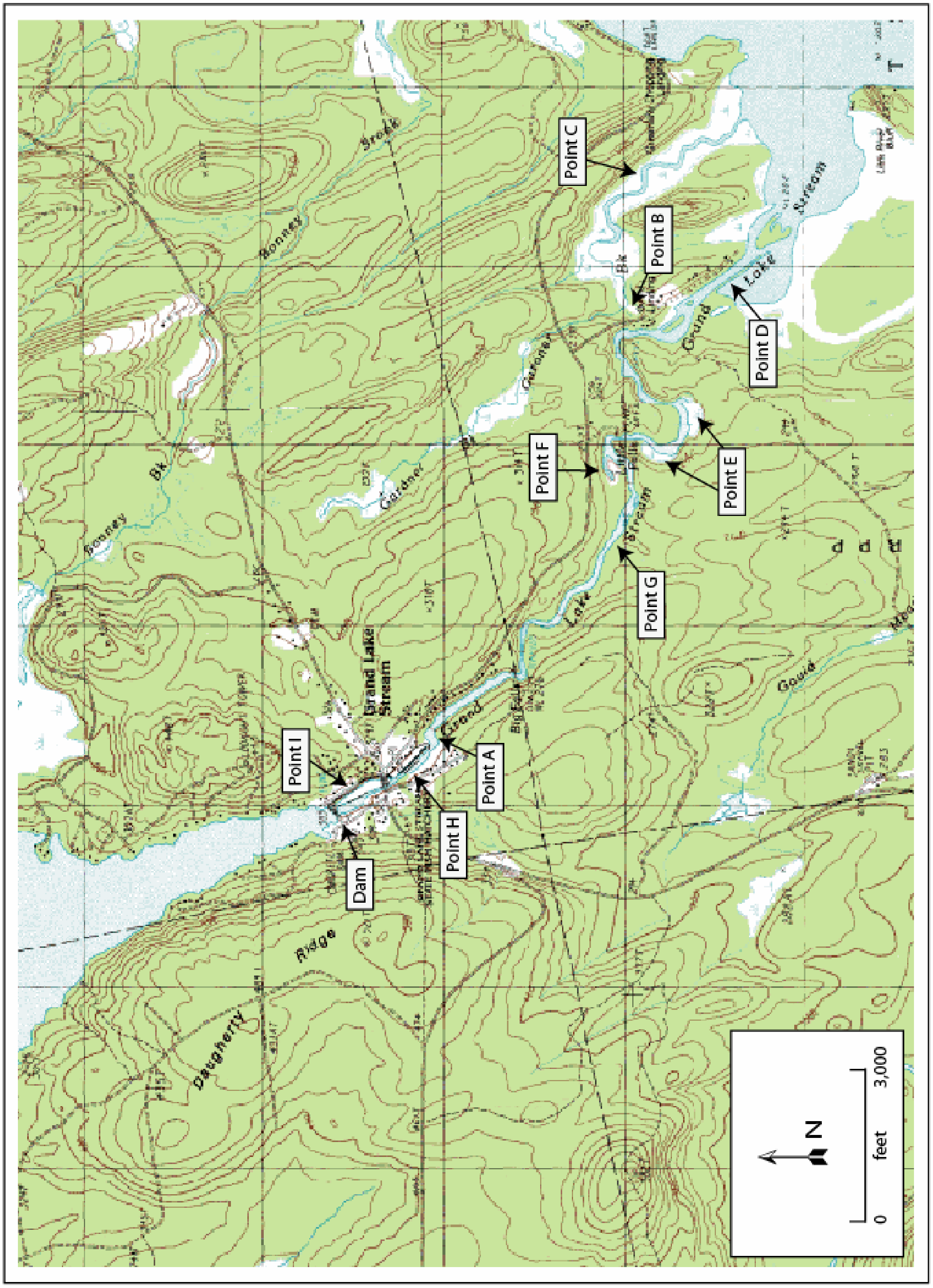
High Eroding Bank

Note: Upstream of Little Falls

Field Geology Services
Fluvial Geomorphology

Grand Lake Stream Fluvial Geomorphology Assessment – Figure 4

Channel Changes on Grand Lake Stream

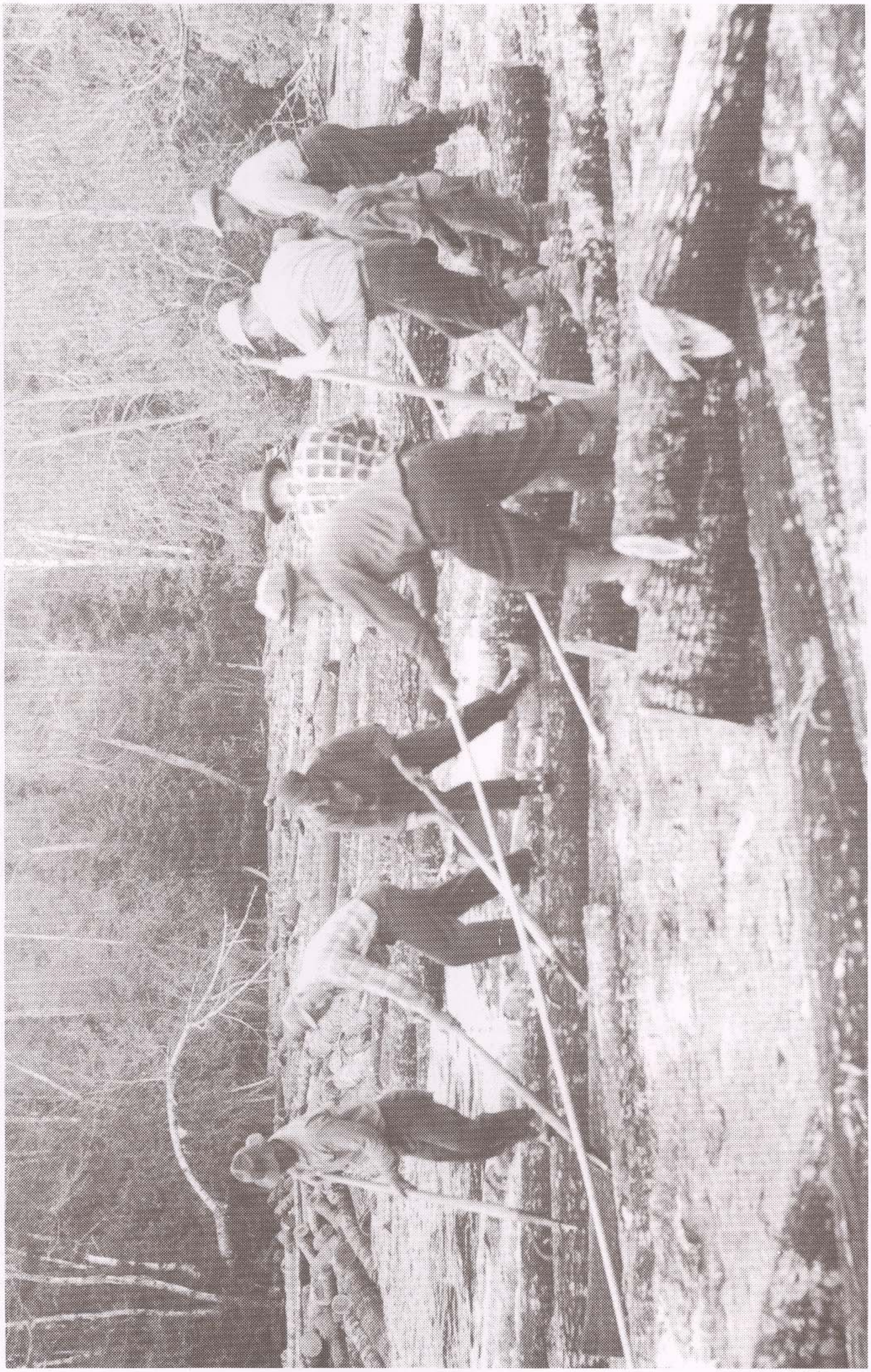


Note: See text for description of lettered points

Grand Lake Stream Fluvial Geomorphology Assessment - Figure 5

Field Geology Services

LOG JAM ON STREAM BELOW BIG FALLS – 1948



Courtesy of Grand Lake Stream Historical Society

Field Geology Services
Fluvial Geomorphology

Grand Lake Stream Fluvial Geomorphology Assessment – Figure 6

Canal to Fish Hatchery and Old Tannery

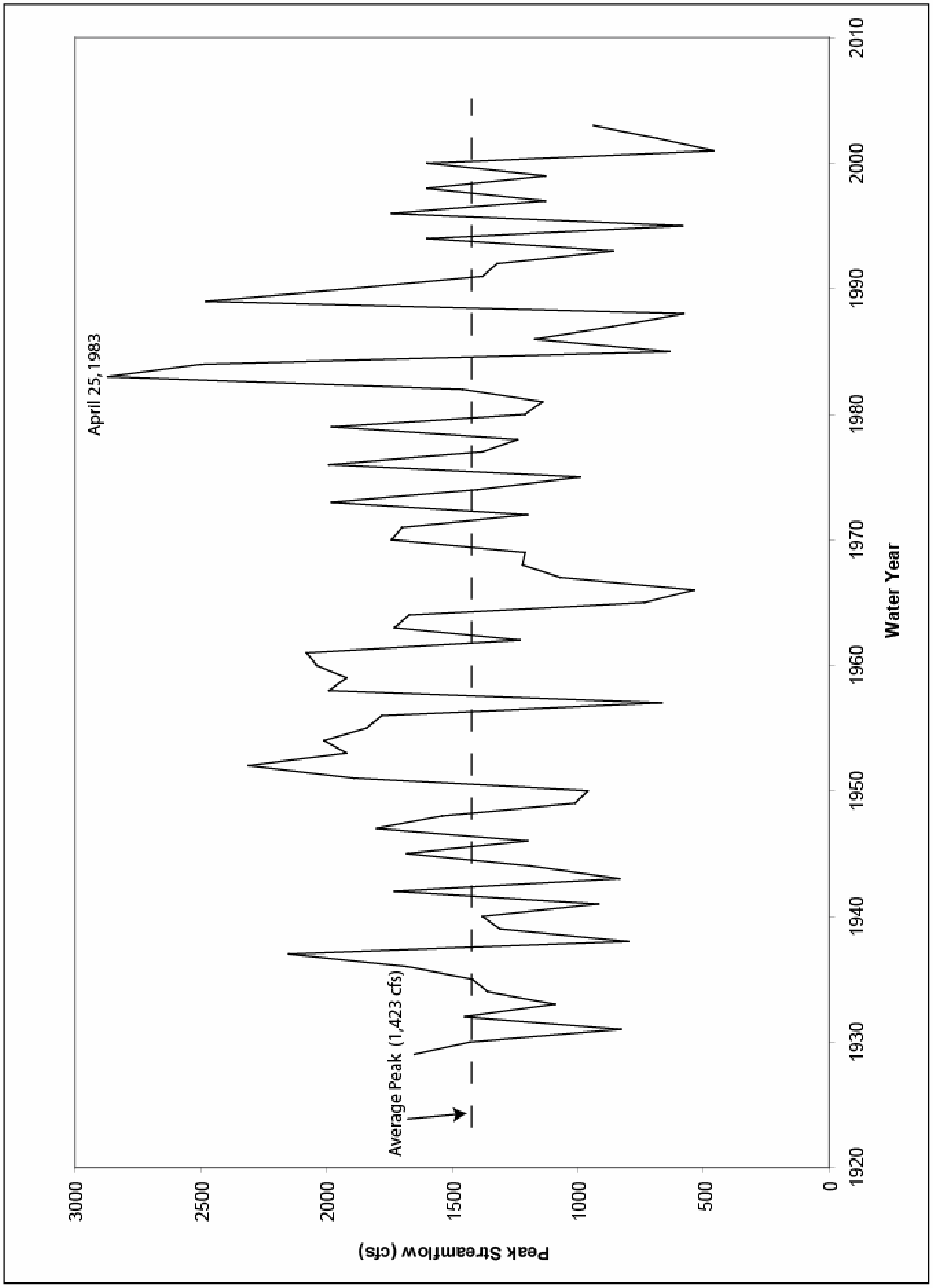
Field Geology Services
Fluvial Geomorphology

Grand Lake Stream Fluvial Geomorphology Assessment – Figure 7

Grand Lake Stream Upstream of Little Falls in 1917

Field Geology Services
Fluvial Geomorphology

Grand Lake Stream Fluvial Geomorphology Assessment – Figure 8



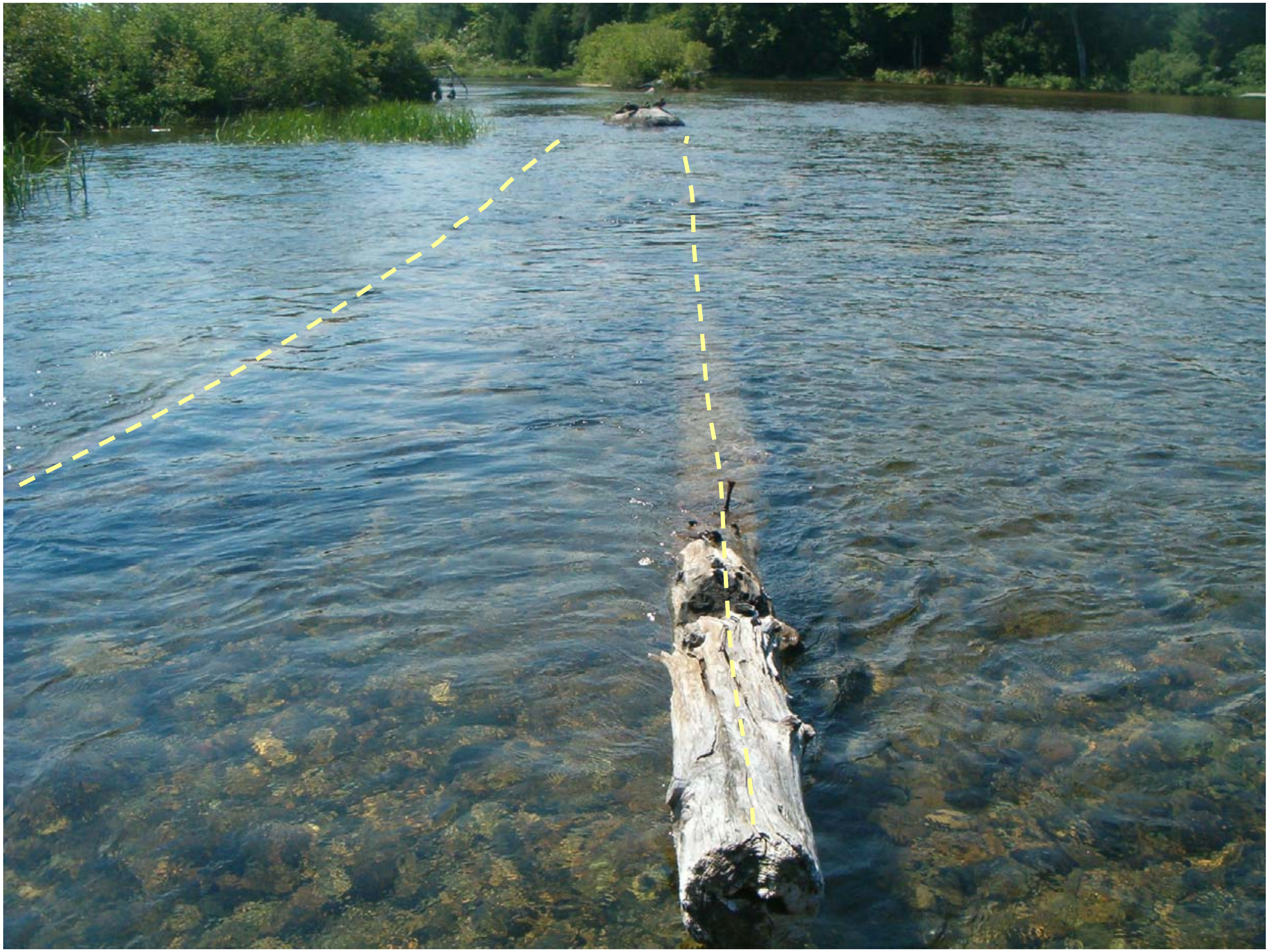
Grand Lake Stream Fluvial Geomorphology Assessment - Figure 9

Erosion Downstream of Dam

Field Geology Services
Fluvial Geomorphology

Grand Lake Stream Fluvial Geomorphology Assessment – Figure 10

Old Channel Constrictor in Disrepair



Note: Dashed lines represent outer margins of log cribbing that comprised the constrictor

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Fluvial Geomorphology

Grand Lake Stream Fluvial Geomorphology Assessment – Figure 11

Study Reach 1

Note: Looking upstream from Big Falls

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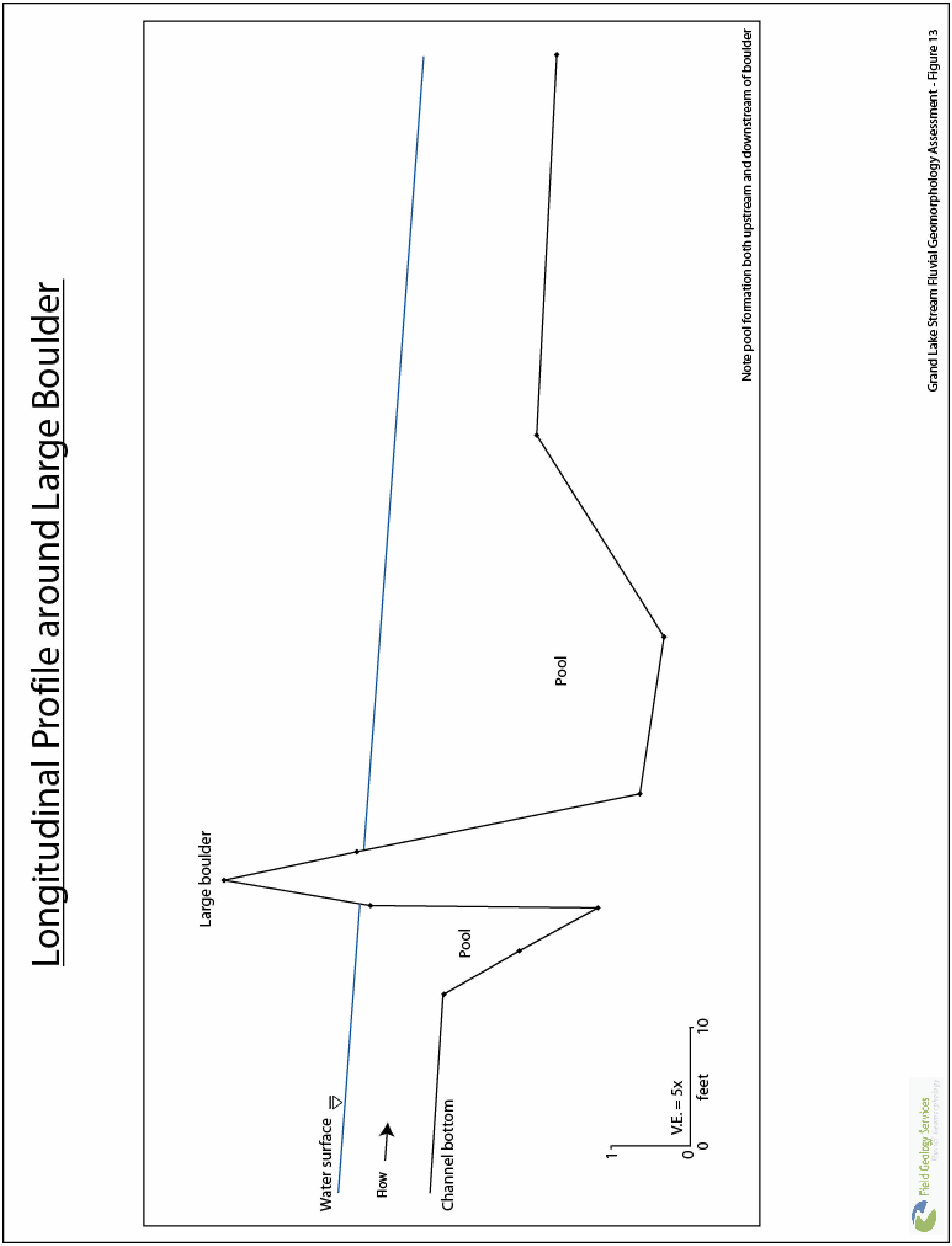
Grand Lake Stream Fluvial Geomorphology Assessment – Figure 12


Longitudinal Profile around Large Boulder
Large boulder
Pool
Pool
Water surface
Flow
Channel bottom
V.E. = 5x
1
0
0
feet
10
Note pool formation both upstream and downstream of boulder
Grand Lake Stream Fluvial Geomorphology Assessment - Figure 13
Field Geology Services

Study Reach 2

Note mid-channel bar forming in center of straightened channel

Field Geology Services
Fluvial Geomorphology

Grand Lake Stream Fluvial Geomorphology Assessment – Figure 14

Study Reach 3

Note: Looking downstream from dock at Kolemook Camp. Low bank on right of channel is artificial channel constrictor

Field Geology Services Fluvial Geomorphology

Grand Lake Stream Fluvial Geomorphology Assessment – Figure 15

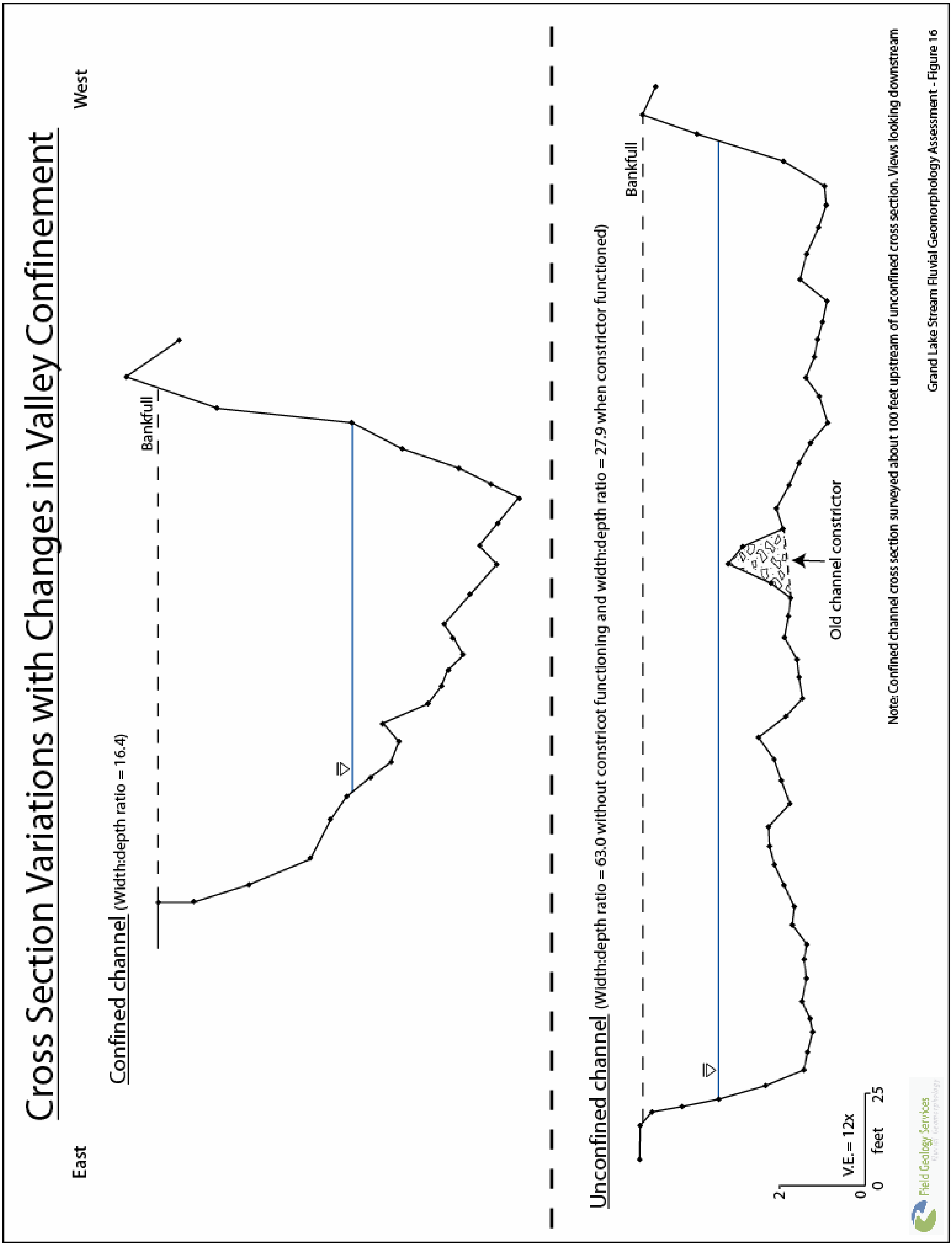

Cross Section Variations with Changes in Valley Confinement
East
West
Confined channel (Width:depth ratio = 16.4)
Bankfull
Unconfined channel (Width:depth ratio = 63.0 without constricot functioning and width:depth ratio = 27.9 when constrictor functioned)
Bankfull
Old channel constrictor
V.E. = 12x
2
0
0
feet
25
Note: Confined channel cross section surveyed about 100 feet upstream of unconfined cross section. Views looking downstream
Grand Lake Stream Fluvial Geomorphology Assessment - Figure 16
Field Geology Services

Table 1. Summary statistics of channel features mapping on Grand Lake Stream

Feature/Characteristic	Left Bank Length (ft)	% Length	Right Bank Length (ft)	% Length	Channel/Totals Length (ft)	% Length	# of Features
Length of channel					18,181	100.0	
Length of channel banks	18,397	100.0	18,560		36,957	100.0	
Bank Composition							
Alluvial	13,039	70.9	10,872	58.6	23,911	64.7	
Nonalluvial	3,654	19.9	5,783	31.2	9,437	25.5	
Bedrock	1,696	9.2	1,899	10.2	3,595	9.7	
Bank Stability							
Eroding	738	4.0	206	1.1	944	2.6	
Riprap	1,595	8.7	581	3.1	2,176	5.9	
Stable	16,063	87.3	17,772	95.8	33,835	91.6	
Riparian Buffer Width							
0 ft	935	5.1	0	0.0	935	2.5	
1-50 ft	942	5.1	266	1.4	1,208	3.3	
50-100 ft	351	1.9	0	0.0	351	0.9	
100-150 ft	2,340	12.7	0	0.0	2,340	6.3	
150-200 ft	1,207	6.6	1,611	8.7	2,818	7.6	
> 200 ft	12,622	68.6	16,683	89.9	29,305	79.3	
Depositional Features							
Mid-channel bars					1,210	6.7	
Side bars					223	1.2	
Substrate Particle Size							
Bedrock					1,736	9.5	
Boulder					0	0.0	
Cobble					10,451	57.5	
Gravel					2,422	13.3	
Sand					3,576	19.7	
Point Features							
Dams							1
Bridges							1
Canal							1
Deflectors/constrictors*							5
Rock ramps							1
Side channels*							5

* The upstream end of these features is marked on the GIS data set (Appendix 2)

Table 2. Summary of channel morphology characteristics on Grand Lake Stream study reaches

Study Reach	Slope (ft/ft)	Sinupsity	Bankfull Width (ft)	Bankfull Depth (ft)	Width:Depth Ratio (ft/ft)	Residual Pool Depth (ft)*	Average Pool Spacing (ft)	Pool Spacing/ Bankfull Width
Reach 1	0.0016	1.0	183	6	30.5	3.5	243	1.3
Reach 2	0.0021	1.0	166	5.2	31.9	2.8	480	2.9
Reach 3	0.0001	1.1	274	4.4	62	2.2	887	3.2

* Residual pool depth is the difference in elevation between the channel bottom at the upstream end of the pool and the deepest part of the pool. The maximum residual pool depth in the reach is shown.

Table 3. Analysis of stream competence to transport median substrate particle size at bankfull discharge

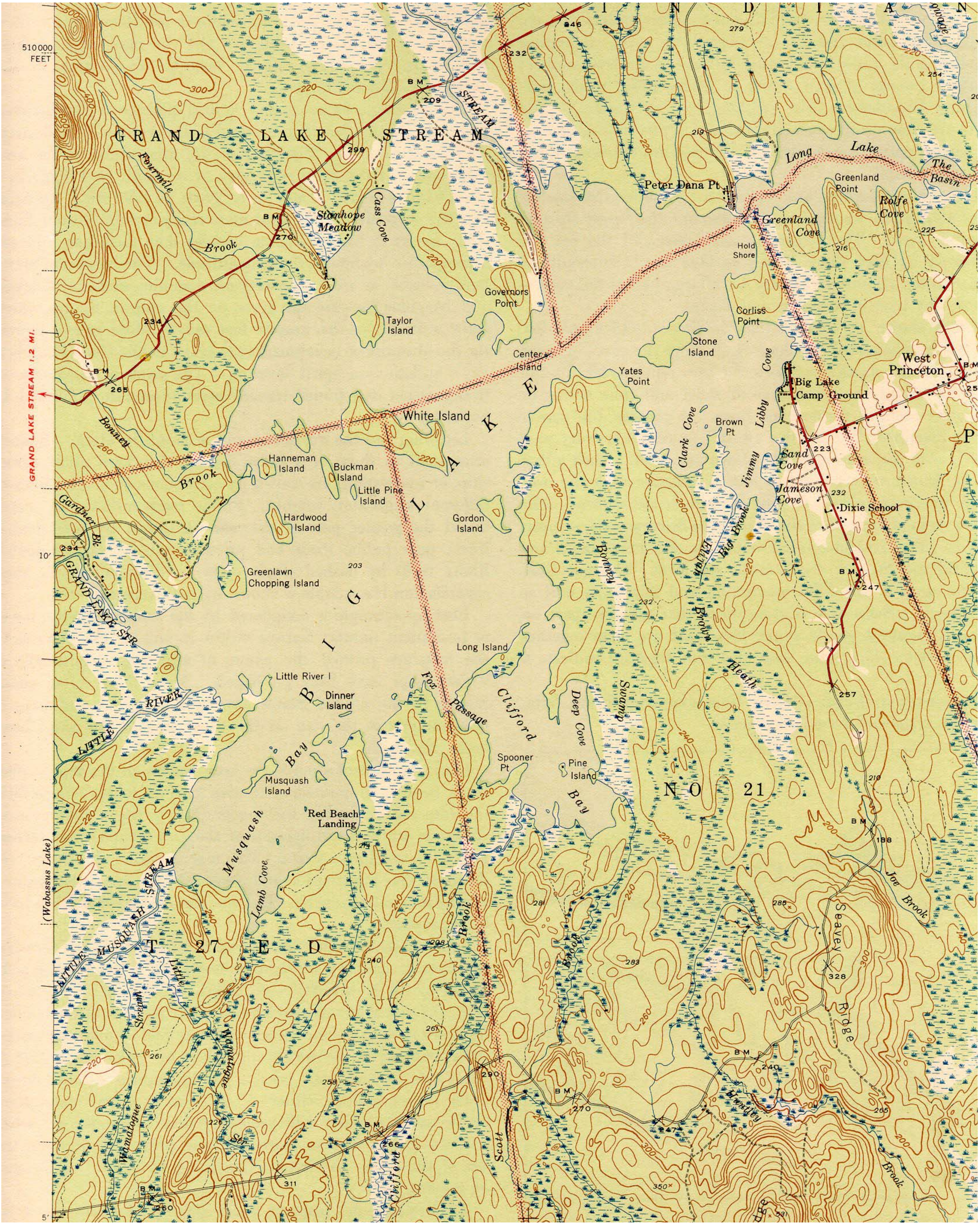
Study Reach	Slope (ft/ft)	Bankfull Depth (ft)	Shear Stress (N/m^2)	D_{50} (m)*	Percent Sand or Finer (%)	Critical Shear Stress (N/m^2)	Particle Motion**
Reach 1	0.0016	183	28.69	0.0553	16	52.03	No
Reach 2	0.0021	166	32.52	0.0261	9	24.55	Yes
Reach 3	0.0001	274	1.31	0.0064	18	6.02	No

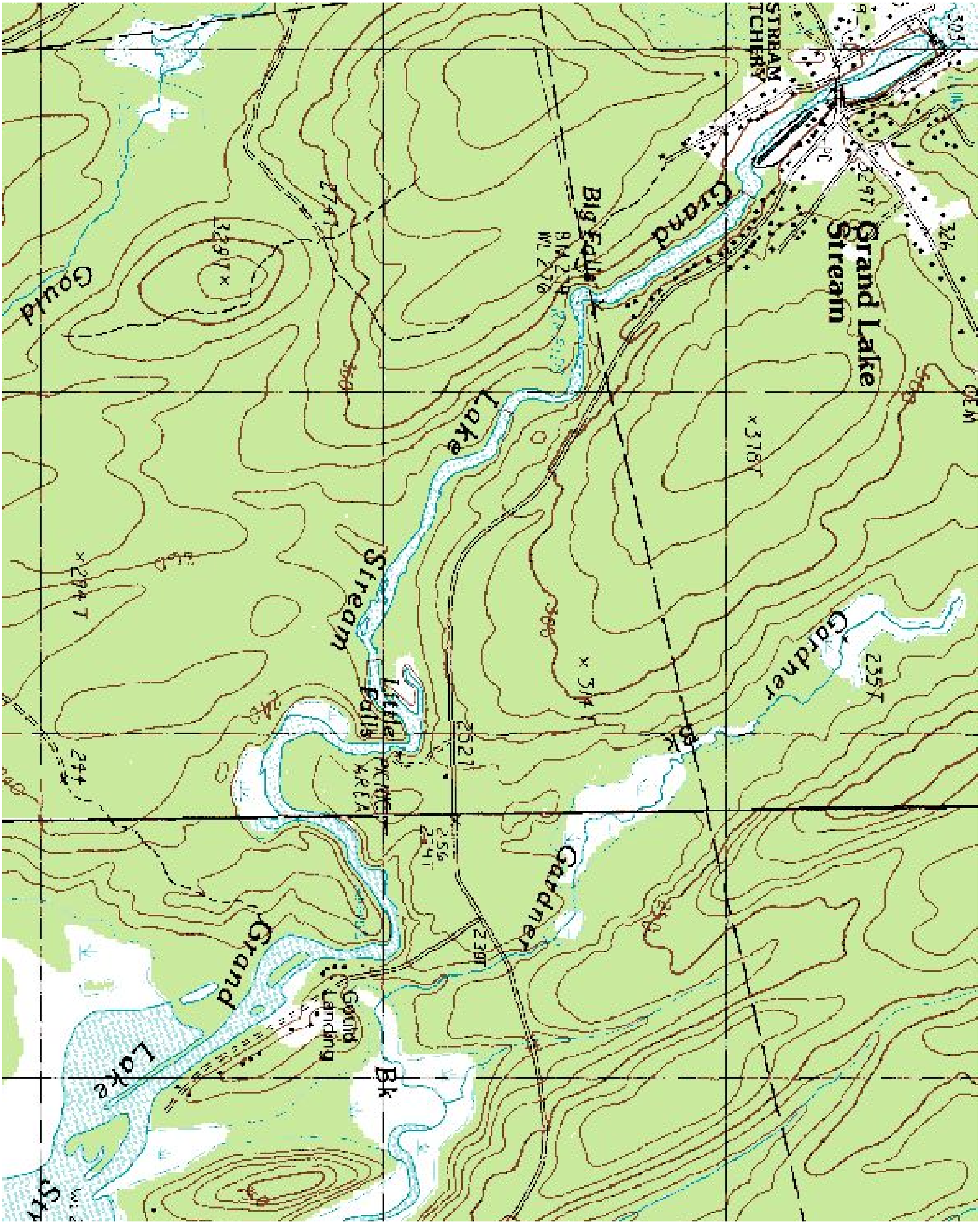
* Median particle size
** Particle motion initiated when shear stress greater than critical shear stress

APPENDIX 1

Historical Topographic Maps


LAKE
T 6 N D
Steamboat Cove
Norway Point
Birch Island
The Cut
Jumbo Landing
Indian Landing
Farm Cove
Big Mayberry Cove
Kole Kill Island
Little Mayberry Cove
FARM COVE DAM
Farm Cove Mtn
Grand Lake Brook
The Burn
Daugherty Ridge
Dyer Cove
Dyer Cove Pt
Kitchen Cove
Kitchen Cove Point
Dyer Cove Ridge
Munson Island
Bonney Brook Lake
FIRETOWER
GRAND LAKE STREAM
Pond Lake
Bonney Bk
Gardner Bk
Grand Lake Stream
Big Falls
Little Falls
JUNC. U. S. NO. 1 8.6 MI.
CALAIS 31.3 MI. HOULTON 76 MI.
Lake
Elsemore Landing
Rolfe Brook
Otter Point
Wabassus Lake
Little River Lake
Gould
Meadow Bk
Little River Mountain
South Mtn
LITTLE RIVER
Burnt Point
Getchel Lakes
Wabassus Mtn
Towers Brook
South Br
Machias Lake
Farm Cove
T 43 M D
T 27 E D
(Big Lake)
Prune Island
Nigger Island
White Birch Island
Eastern Arm
Midland Flats
King Brook
South Stream
Branch
Big Ship I
Little Ship I
Norway Island
Cove Mtn
Mutton Cove Bk
Thompson Bk
Mutton Cove
Cherry Tree
Monroe Brook
Monroe Lake
Musquash
Brook


510000 FEET
GRAND LAKE STREAM
GRAND LAKE STREAM 1.2 MI.
Fourmile Brook
Stanhope Meadow
Cass Cove
Governors Point
Taylor Island
Center Island
White Island
BIG LAKE
Hanneman Island
Buckman Island
Little Pine Island
Hardwood Island
Gordon Island
Greenlawn Chopping Island
Long Island
Little River I
Dinner Island
Fox Passage
Clifford
Deep Cove
Spooner Pt
Pine Island
Bay
Musquash Bay
Musquash Island
Red Beach Landing
Musquash
Lamb Cove
LITTLE RIVER
Bonney Brook
Gardner Bk.
Peter Dana Pt
Long Lake
The Basin
Greenland Point
Rolfe Cove
Greenland Cove
Hold Shore
Corliss Point
Stone Island
Yates Point
Clark Cove
Brown Pt
Libby Cove
Jimmy Cove
Big Lake Camp Ground
West Princeton
Sand Cove
Jameson Cove
Dixie School
Big Brook
Bonney
Brown Heath
Swamp
NO 21
T 27 E D
(Wabassus Lake)
LITTLE MUSQUASH STREAM
Little Musquash Stream
Wabadloque
Wabadloque Str
Clifford
Scott Brook
Seavey Ridge
Joe Brook
Brook
Hardin
I N D I A N
P
B M
10′
5′


Grand Lake
Stream
Grand
Big Falls
Gould
Lake
Stream
Little Falls
PICNIC AREA
Gardner
Gardner
Grand
Gould Landing
Lake
Bk

APPENDIX 2

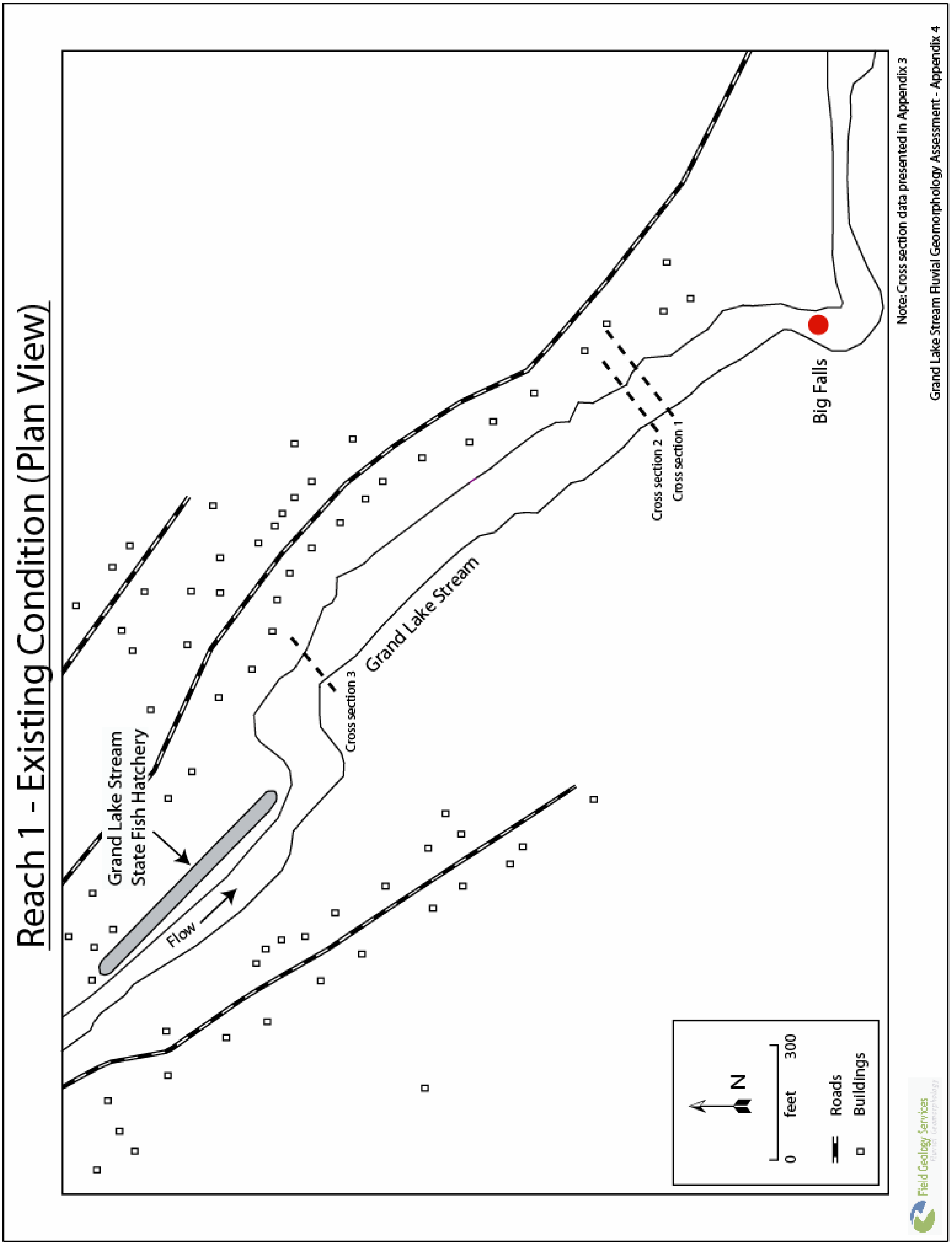
GIS Shapefiles
(see attached CD)

APPENDIX 3

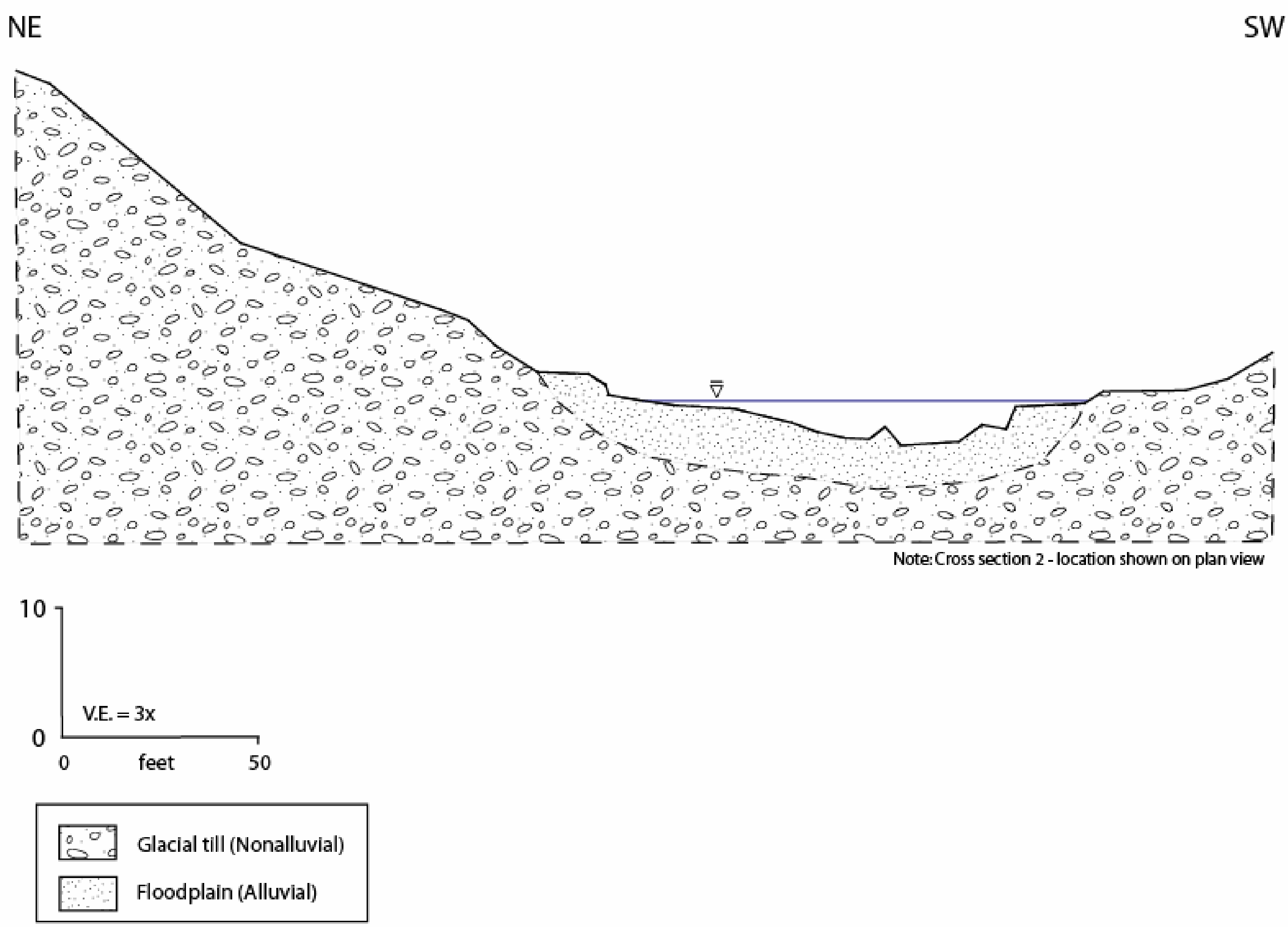
Topographic Surveying and Substrate Particle Size Data
(see attached CD)

APPENDIX 4

Conceptual Restoration Design Options


Reach 1 - Existing Condition (Plan View)
Grand Lake Stream
State Fish Hatchery
Flow
Grand Lake Stream
Cross section 3
Cross section 2
Cross section 1
Big Falls
0
feet
300
N
Roads
Buildings
Note: Cross section data presented in Appendix 3
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services

Reach 1 - Existing Condition (Cross Section)



Note: Cross section 2 - location shown on plan view

Do Nothing Option

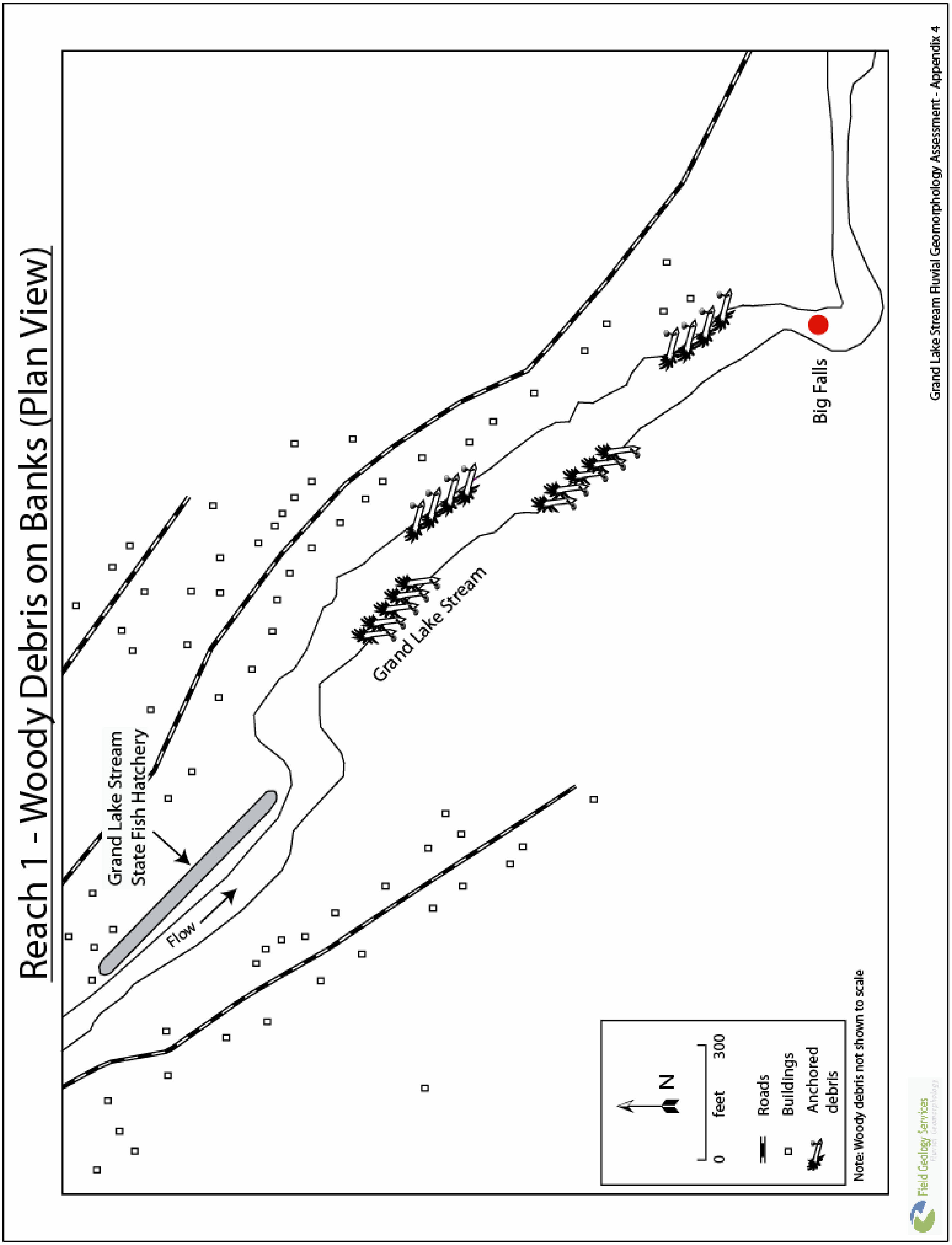
Pros:

- No investment
- No short term construction impacts
- Channel naturally straight and wide

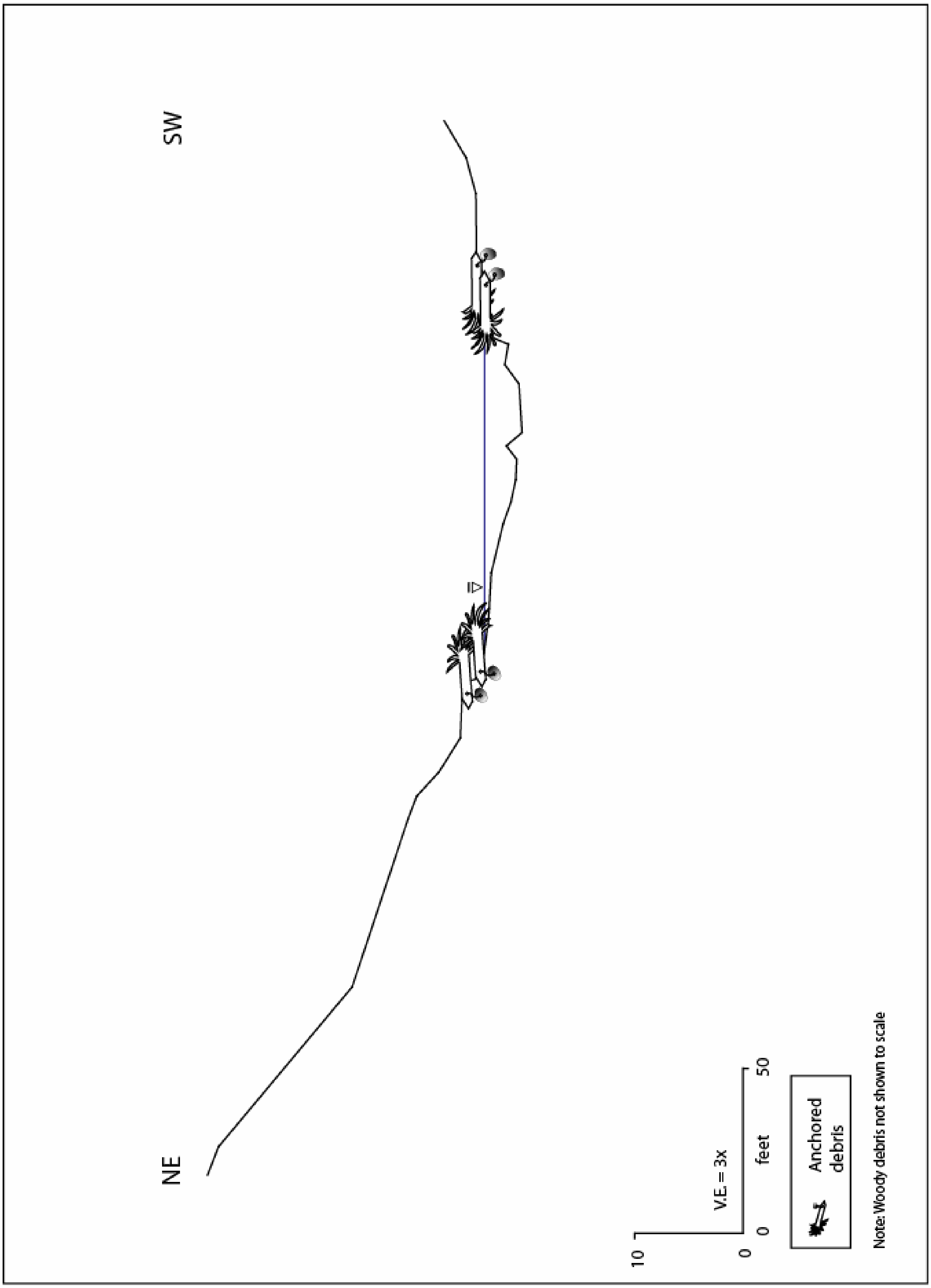
Cons:

- Pool forming elements removed from channel
- Channel armored
- No habitat improvement

Field Geology Services
Fluvial Geomorphology


Reach 1 - Woody Debris on Banks (Plan View)
Grand Lake Stream State Fish Hatchery
Flow
Grand Lake Stream
Big Falls
N
0 feet 300
Roads
Buildings
Anchored debris
Note: Woody debris not shown to scale
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services

Reach 1 - Woody Debris on Banks (Cross Section)



Field Geology Services

Woody Debris on Banks Option

<u>Pros</u>:

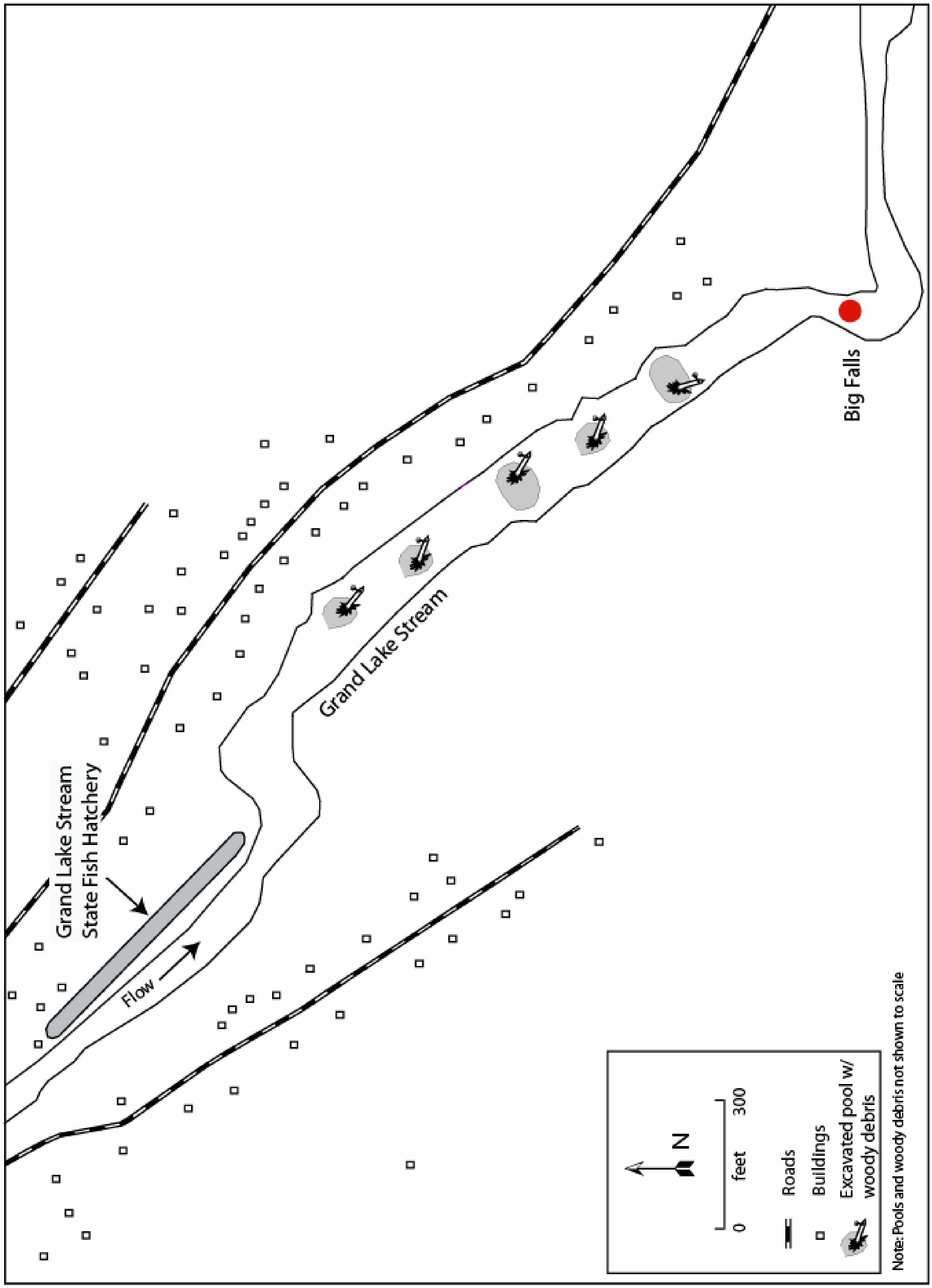
- Creates cover habitat
- Minimal short term impact on channel
- Provide bank stability
- Minor channel narrowing
- Mimics natural debris jams

<u>Cons</u>:

- No pool habitat created
- Channel remains armored
- Financial cost

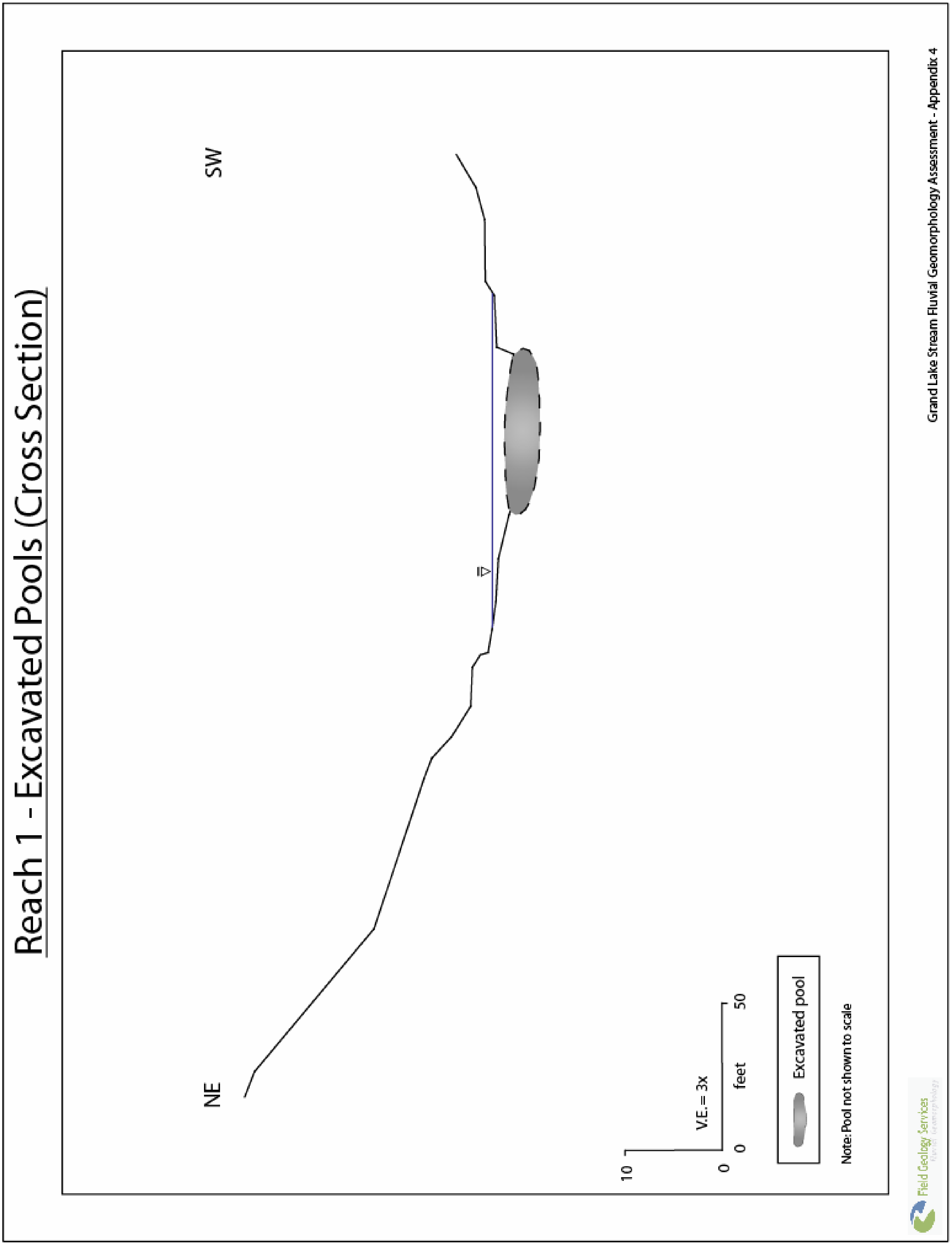
Field Geology Services
Fluvial Geomorphology

Reach 1 - Excavated Pools (Plan View)



Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4

Field Geology Services


Reach 1 - Excavated Pools (Cross Section)
NE
SW
10
0
V.E.= 3x
0
feet
50
Excavated pool
Note: Pool not shown to scale
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services

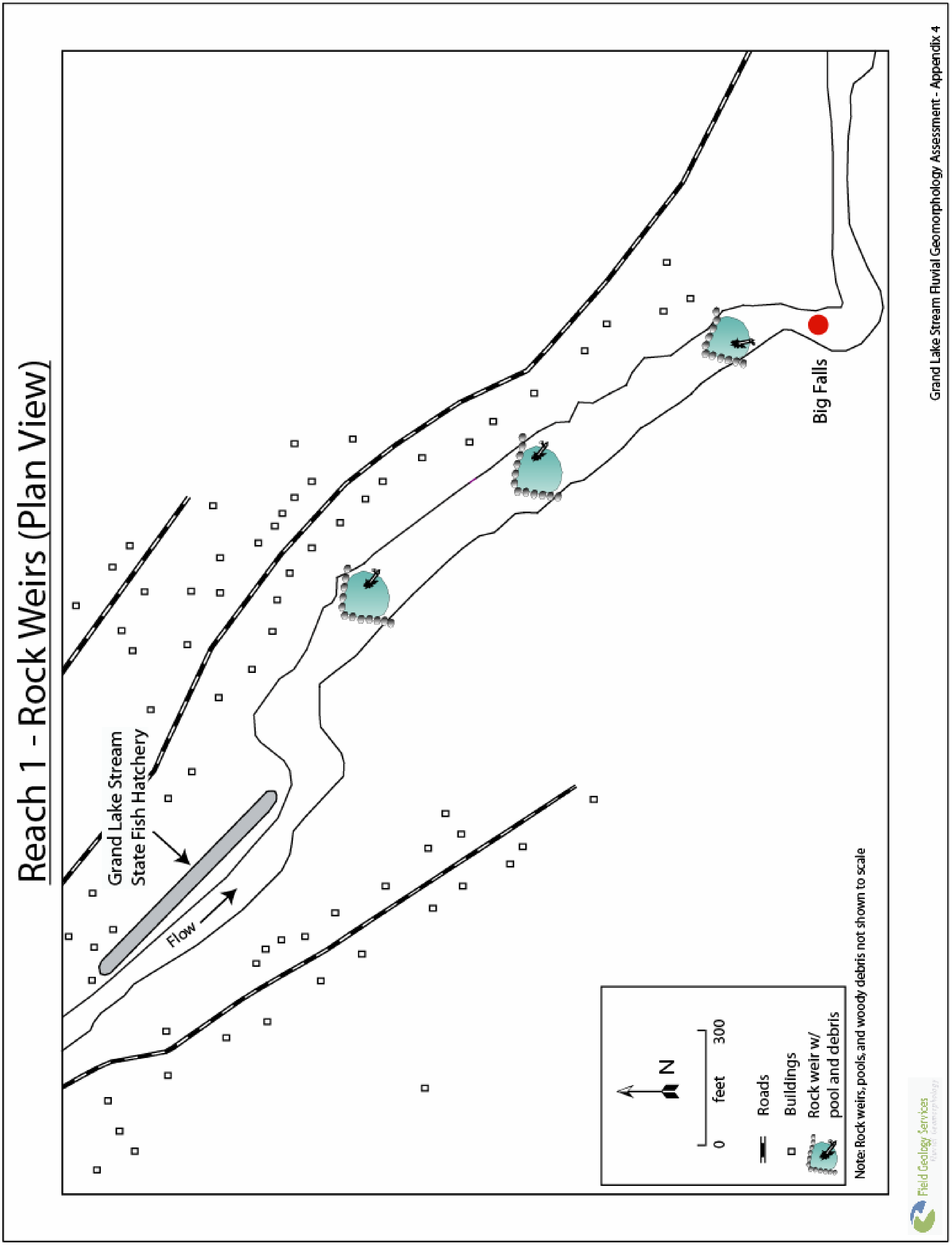
Excavated Pools Option

Pros:

- Creates pool habitat
- Cover habitat if woody debris added

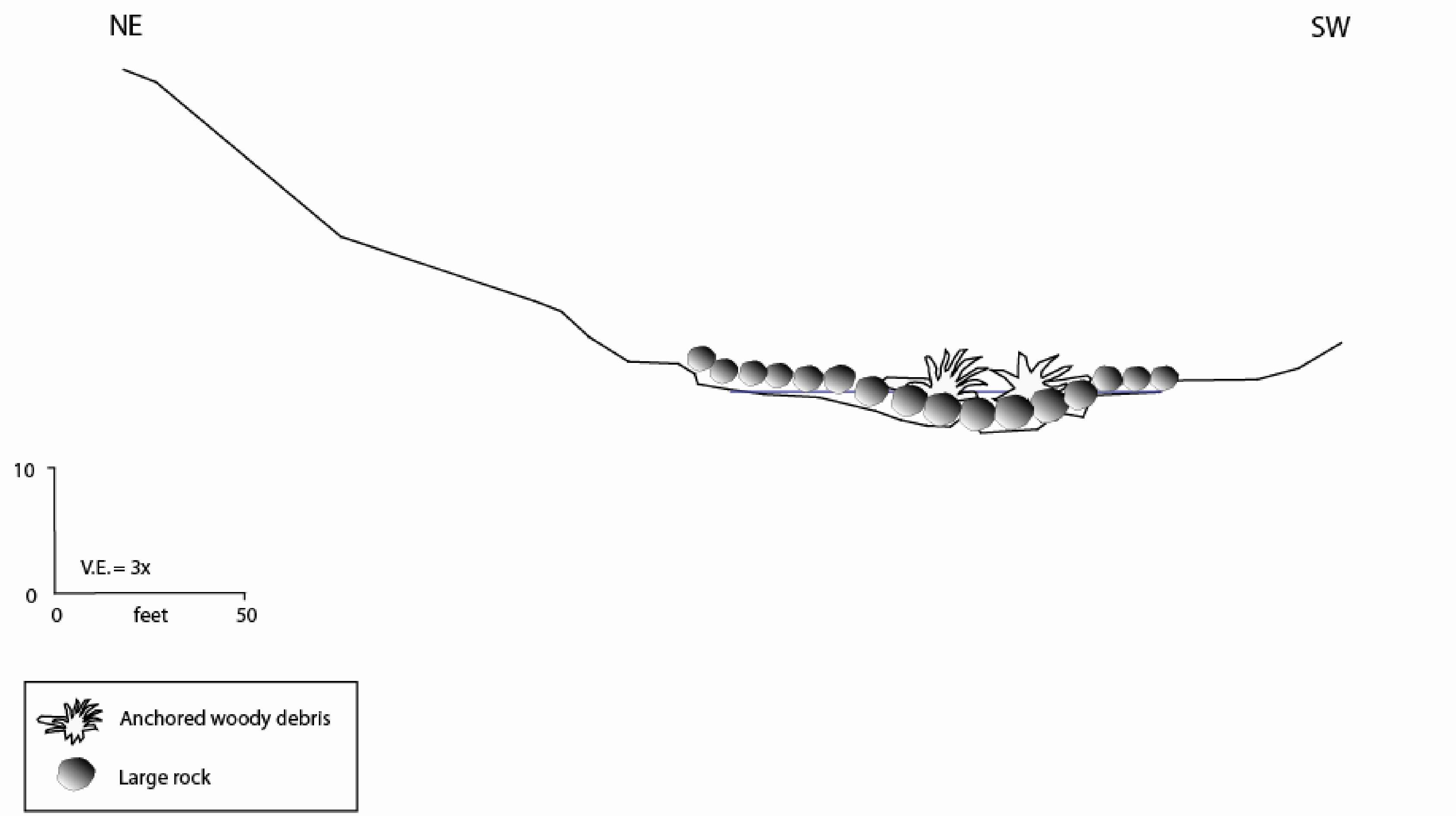
Cons:

- Not sustainable – pools will fill in
- Disturbance of channel bed
- Financial cost



Reach 1 - Rock Weirs (Plan View)
Grand Lake Stream State Fish Hatchery
Flow
Big Falls
N
0 feet 300
Roads
Buildings
Rock weir w/ pool and debris
Note: Rock weirs, pools, and woody debris not shown to scale
Field Geology Services
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4

Reach 1 - Rock Weirs (Cross Section)



Note: Woody debris and rock not shown to scale

Rock Weirs Option

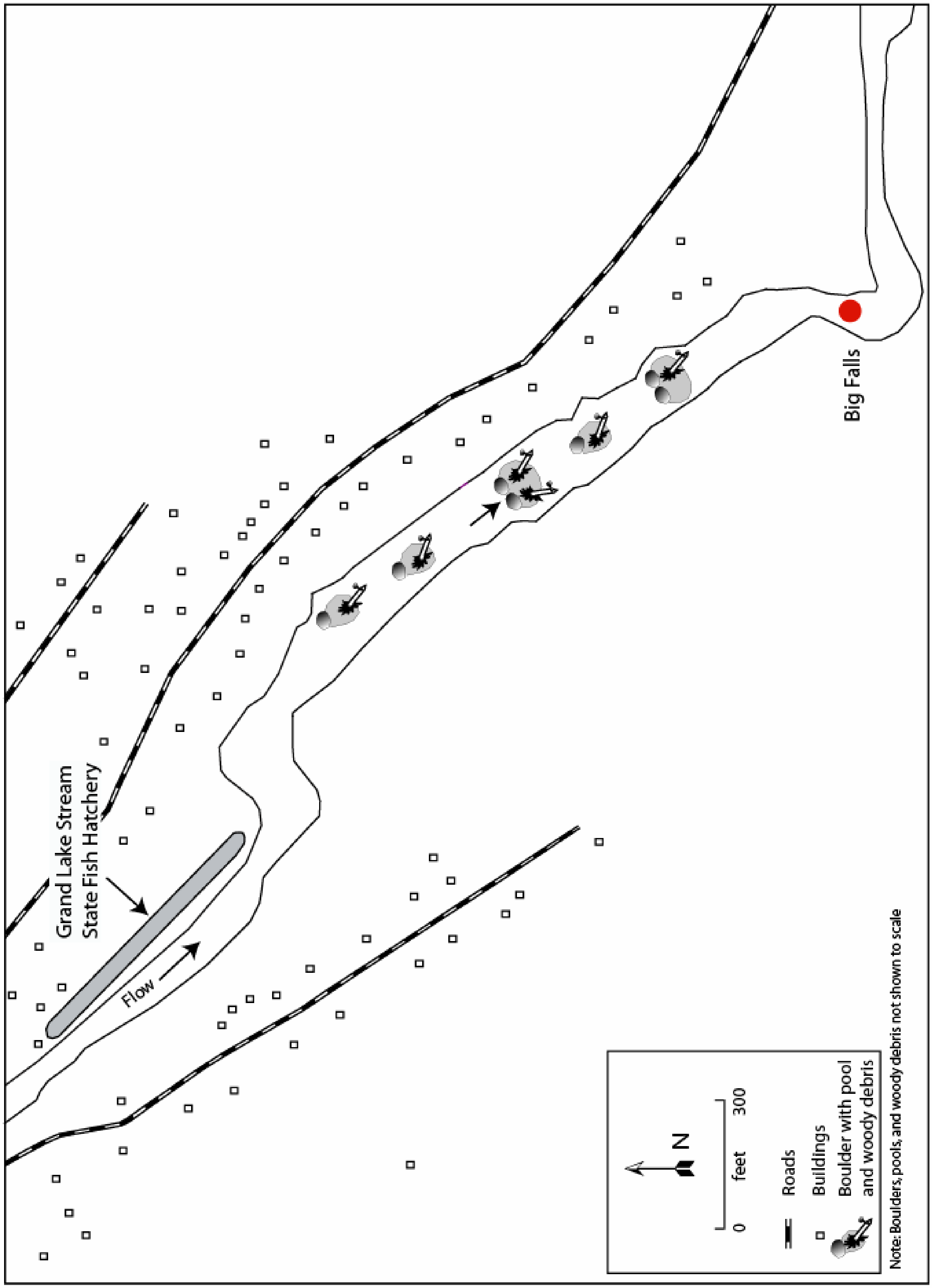
Pros:

- Creates pool habitat
- Cover habitat if woody debris added
- Narrowing of channel

Cons:

- Unnatural appearance
- Disturbance of channel bed
- Financial cost

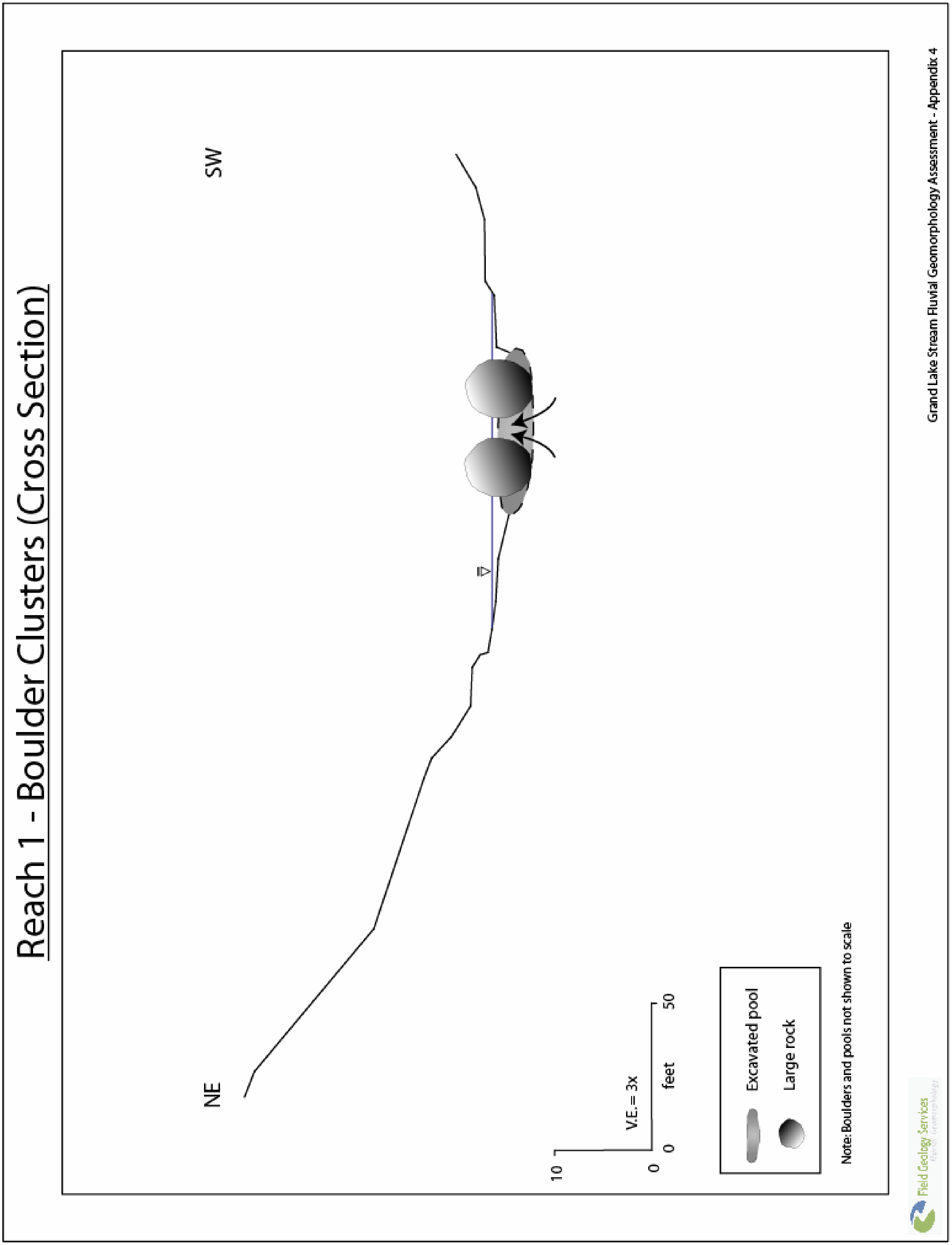
Reach 1 - Boulder Clusters (Plan View)



Note: Boulders, pools, and woody debris not shown to scale

Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4

Field Geology Services


Reach 1 - Boulder Clusters (Cross Section)
NE
SW
V.E.= 3x
10
0
0
feet
50
Excavated pool
Large rock
Note: Boulders and pools not shown to scale
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services

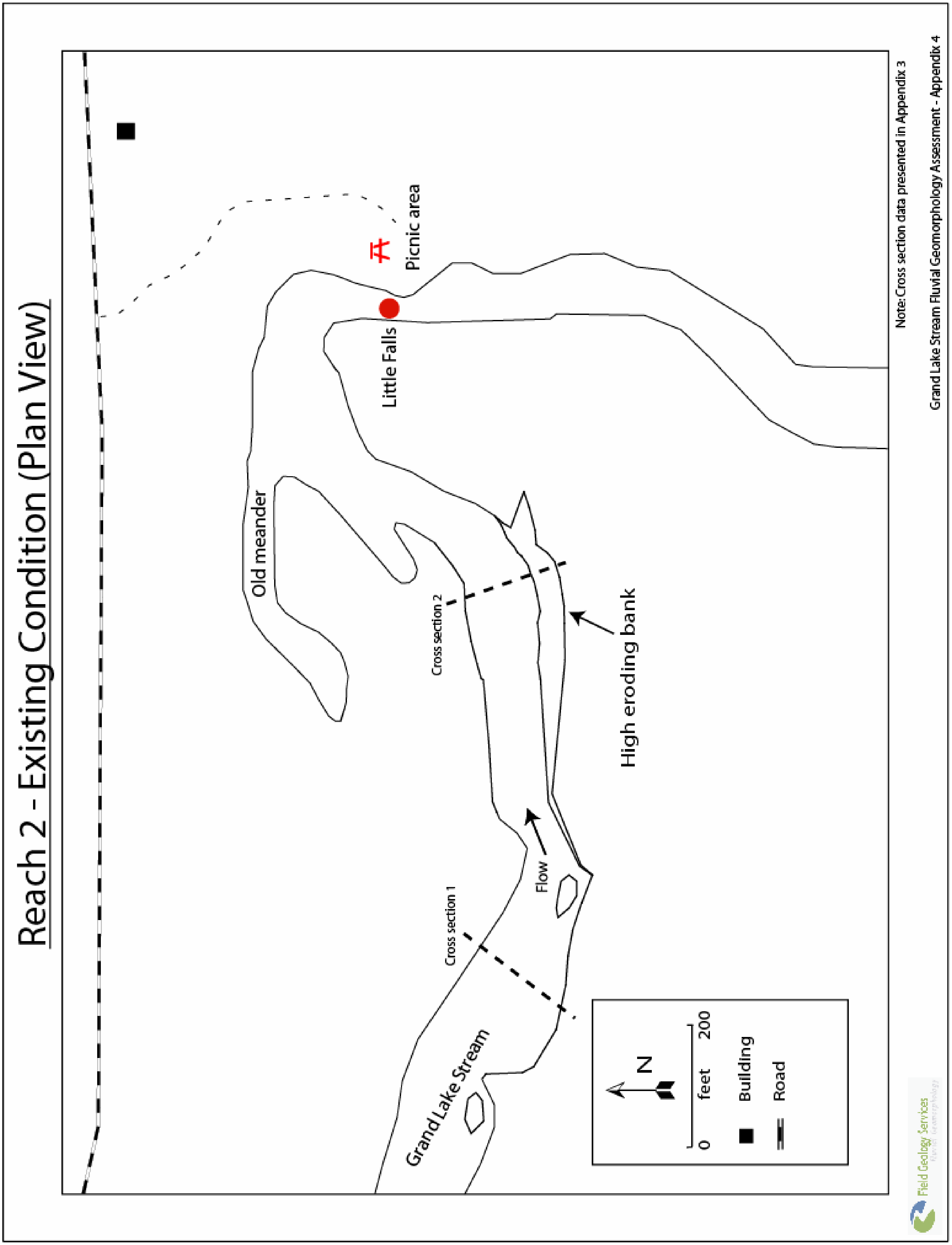
Boulder Clusters Option

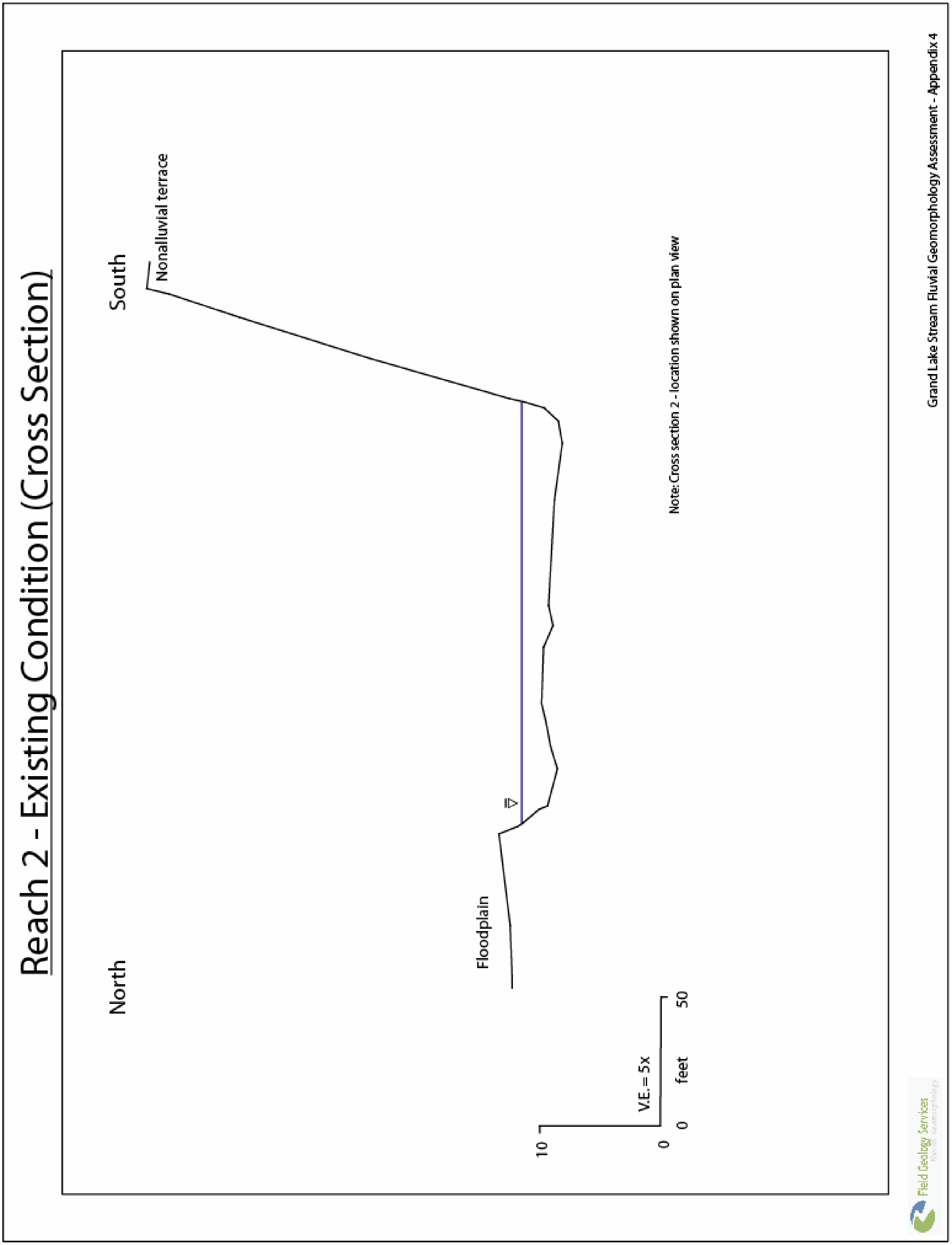
Pros:

- Creates sustainable pool habitat
- Cover habitat if woody debris added
- Restores original morphology

Cons:

- Disturbance of channel bed if pools excavated
- Financial cost


Reach 2 - Existing Condition (Plan View)
Picnic area
Little Falls
Old meander
Cross section 2
High eroding bank
Flow
Cross section 1
Grand Lake Stream
N
0
feet
200
Building
Road
Note: Cross section data presented in Appendix 3
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services


Reach 2 - Existing Condition (Cross Section)
North
South
Nonalluvial terrace
Floodplain
Note: Cross section 2 - location shown on plan view
V.E. = 5x
10
0
0
feet
50
Field Geology Services
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4

Do Nothing Option

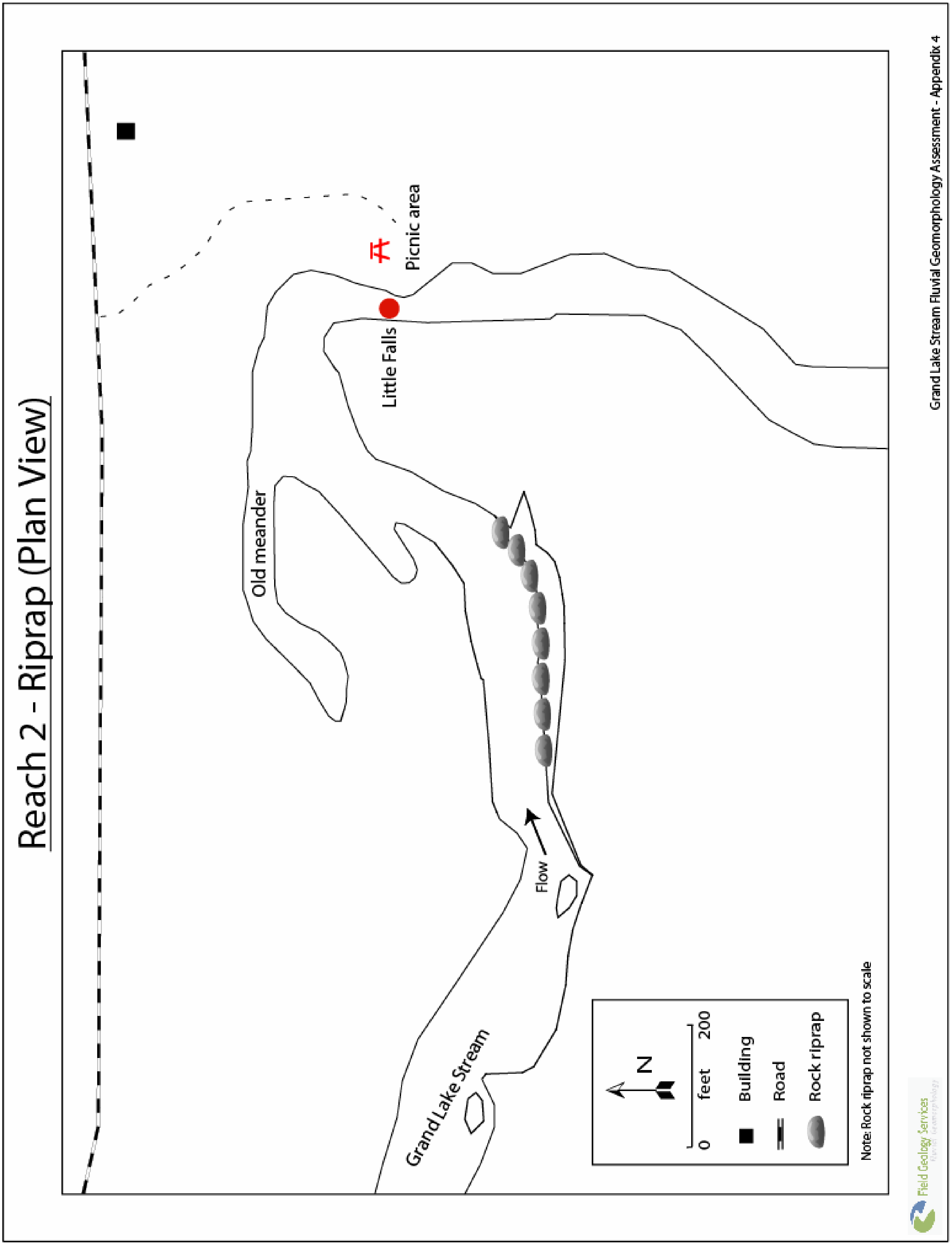
Pros:

- No investment
- No short term construction impacts
- Flow diversion may naturally occur

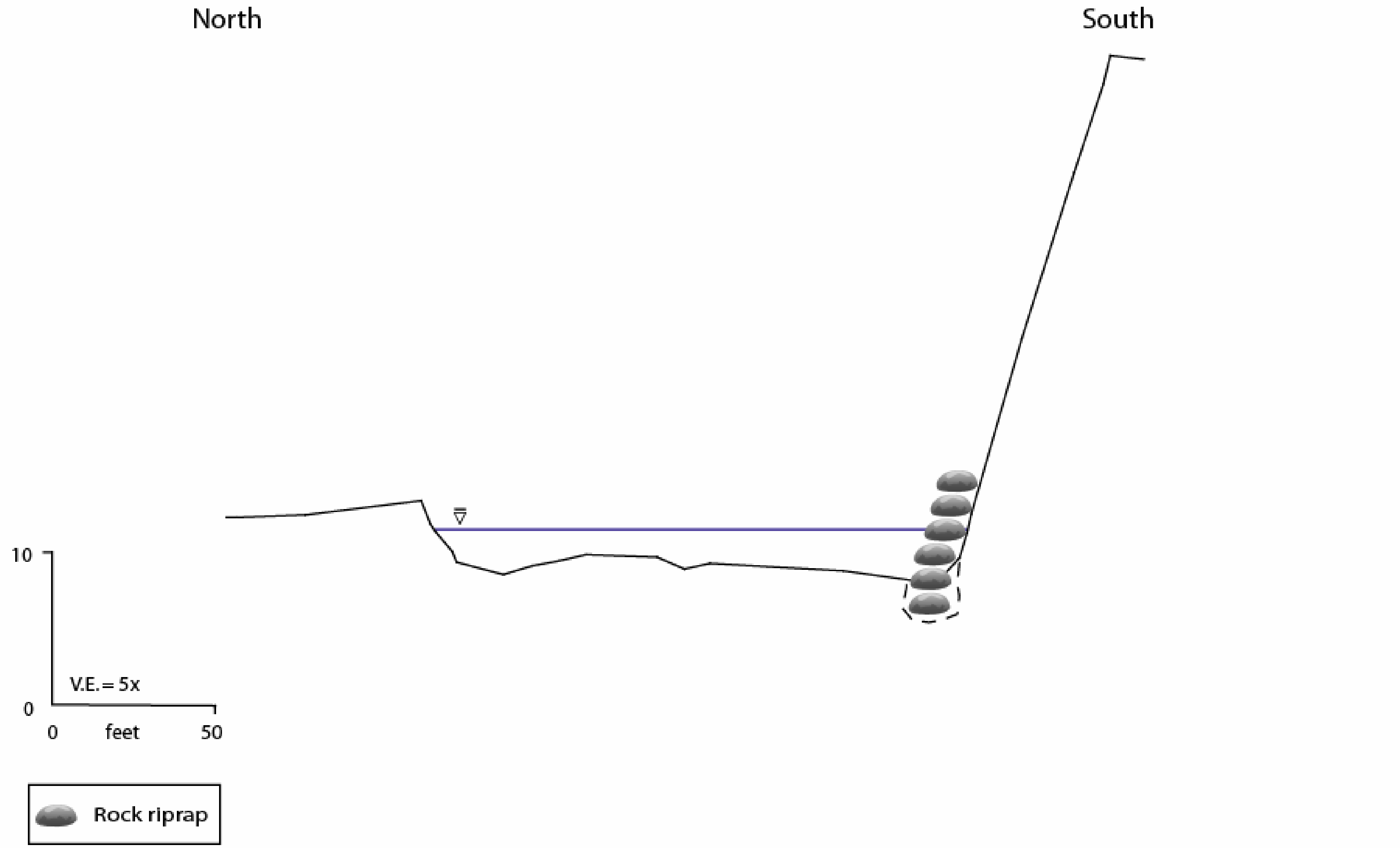
Cons:

- Sedimentation and erosion continues
- No habitat improvement

Field Geology Services
Fluvial Geomorphology


Reach 2 - Riprap (Plan View)
Picnic area
Little Falls
Old meander
Flow
Grand Lake Stream
N
0
feet
200
Building
Road
Rock riprap
Note: Rock riprap not shown to scale
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services

Reach 2 - Riprap (Cross Section)



Note: Rock riprap not shown to scale

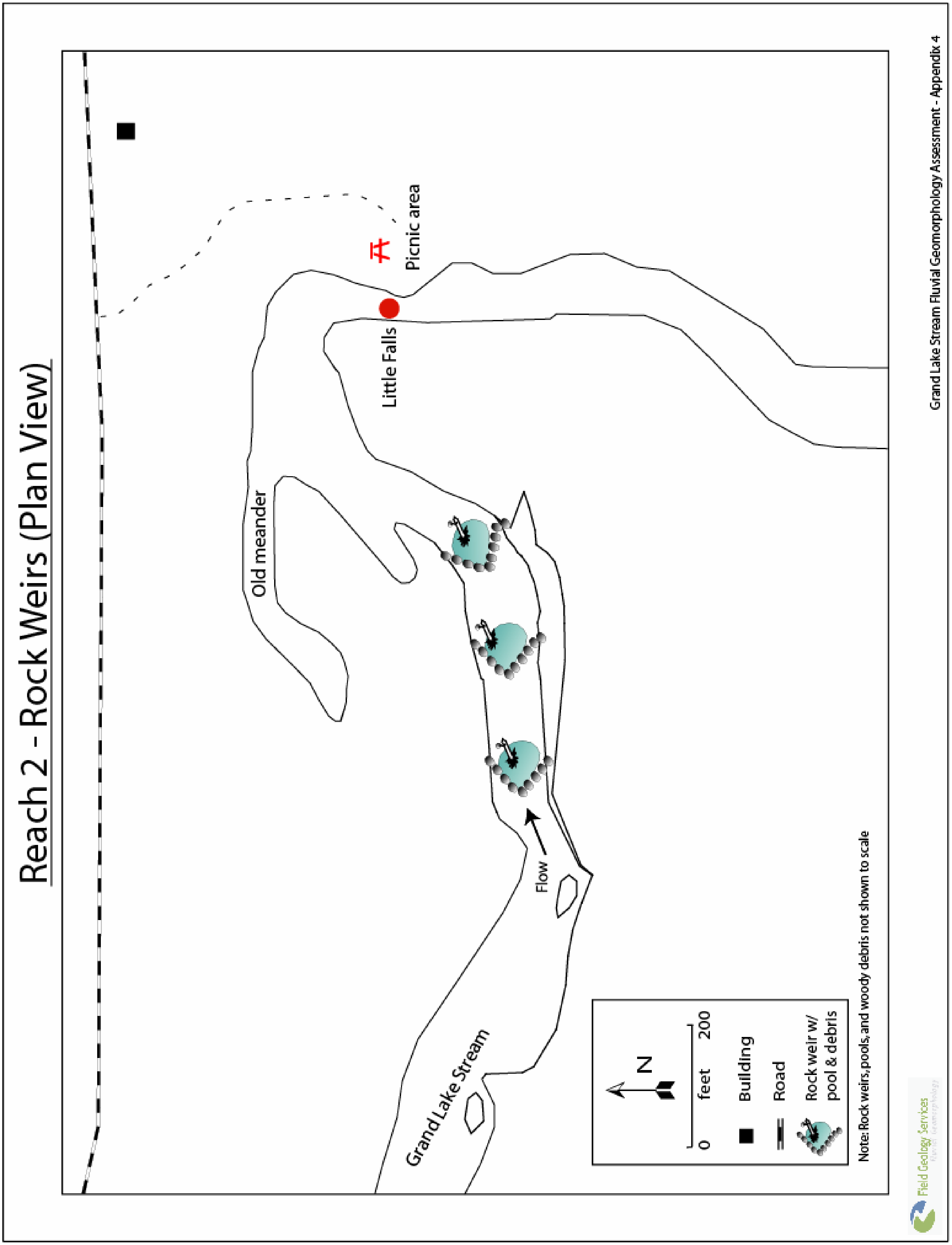
Riprap Option

Pros:

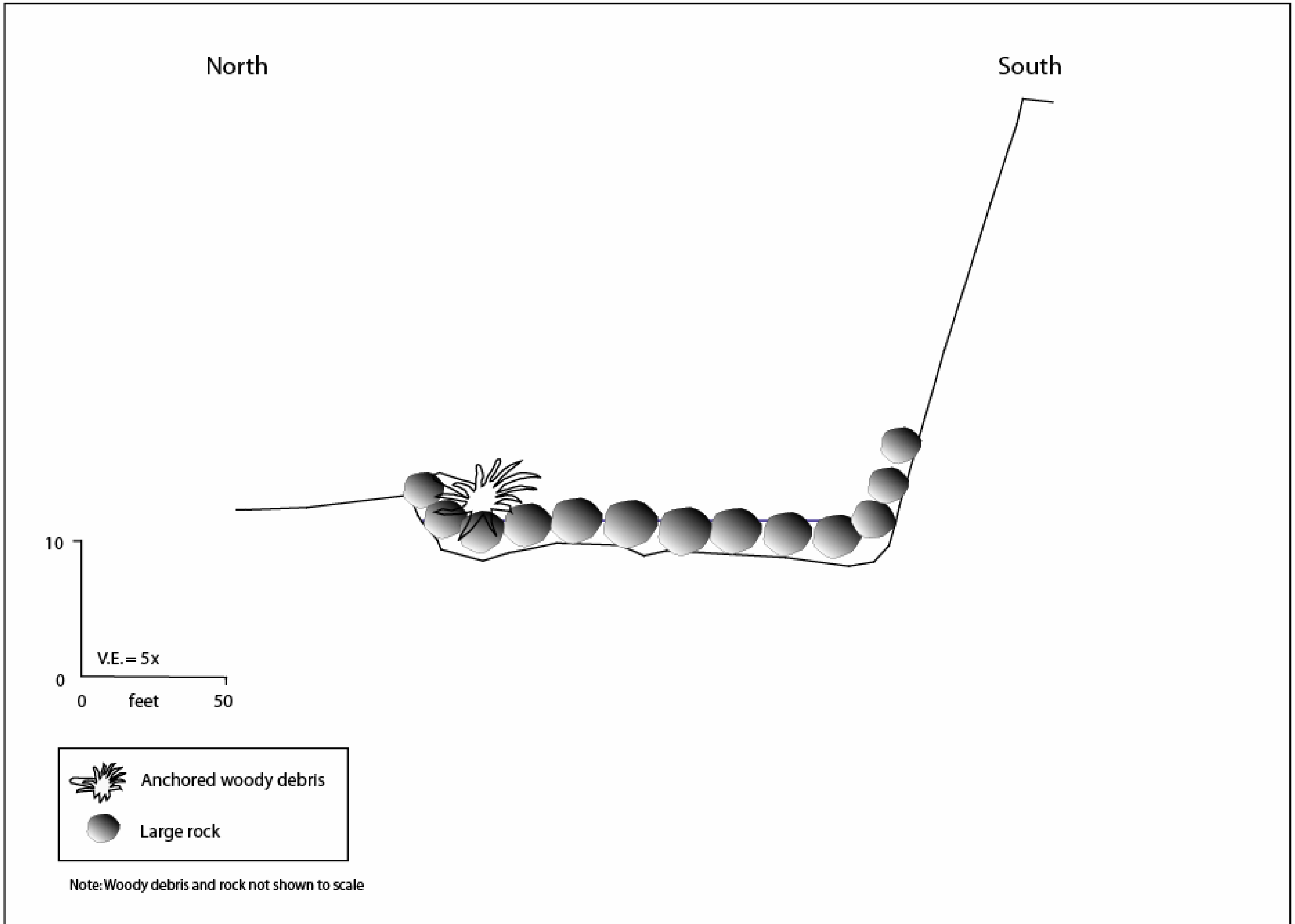
- Arrest erosion of high bank in short term

Cons:

- Limited habitat created
- Destabilize adjacent slopes
- Disturbance in channel
- Financial cost


Reach 2 - Rock Weirs (Plan View)
Picnic area
Little Falls
Old meander
Flow
Grand Lake Stream
N
0 feet 200
Building
Road
Rock weir w/ pool & debris
Note: Rock weirs, pools, and woody debris not shown to scale
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services

Reach 2 - Rock Weirs (Cross Section)



Rock Weirs Option

Pros:

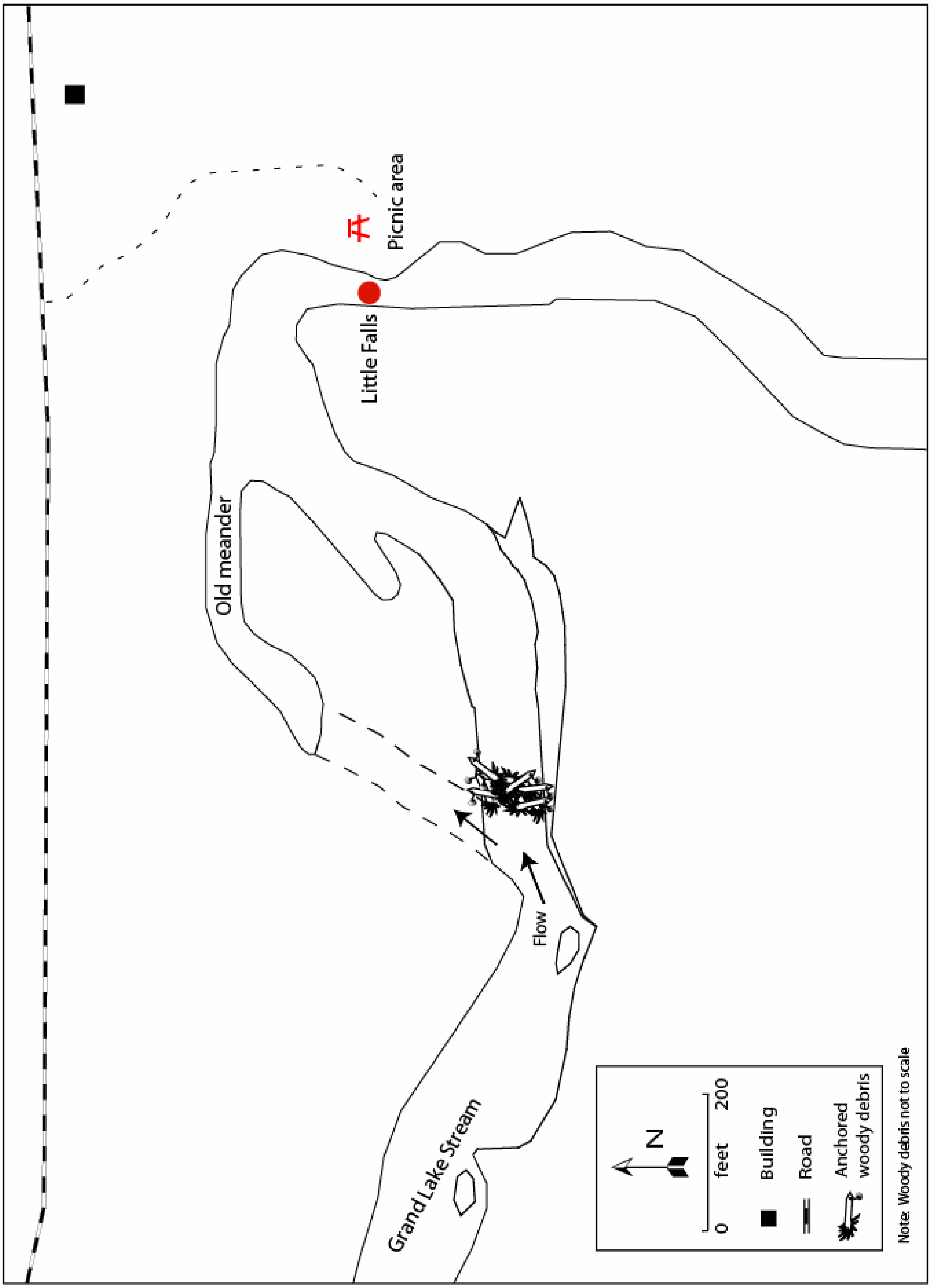
- Creates pool habitat
- Cover habitat if woody debris added
- Narrowing of channel

Cons:

- Unnatural appearance
- Inappropriate setting
- Disturbance of channel bed
- Financial cost

Field Geology Services
Fluvial Geomorphology

Reach 2 - Flow Diversion (Plan View)



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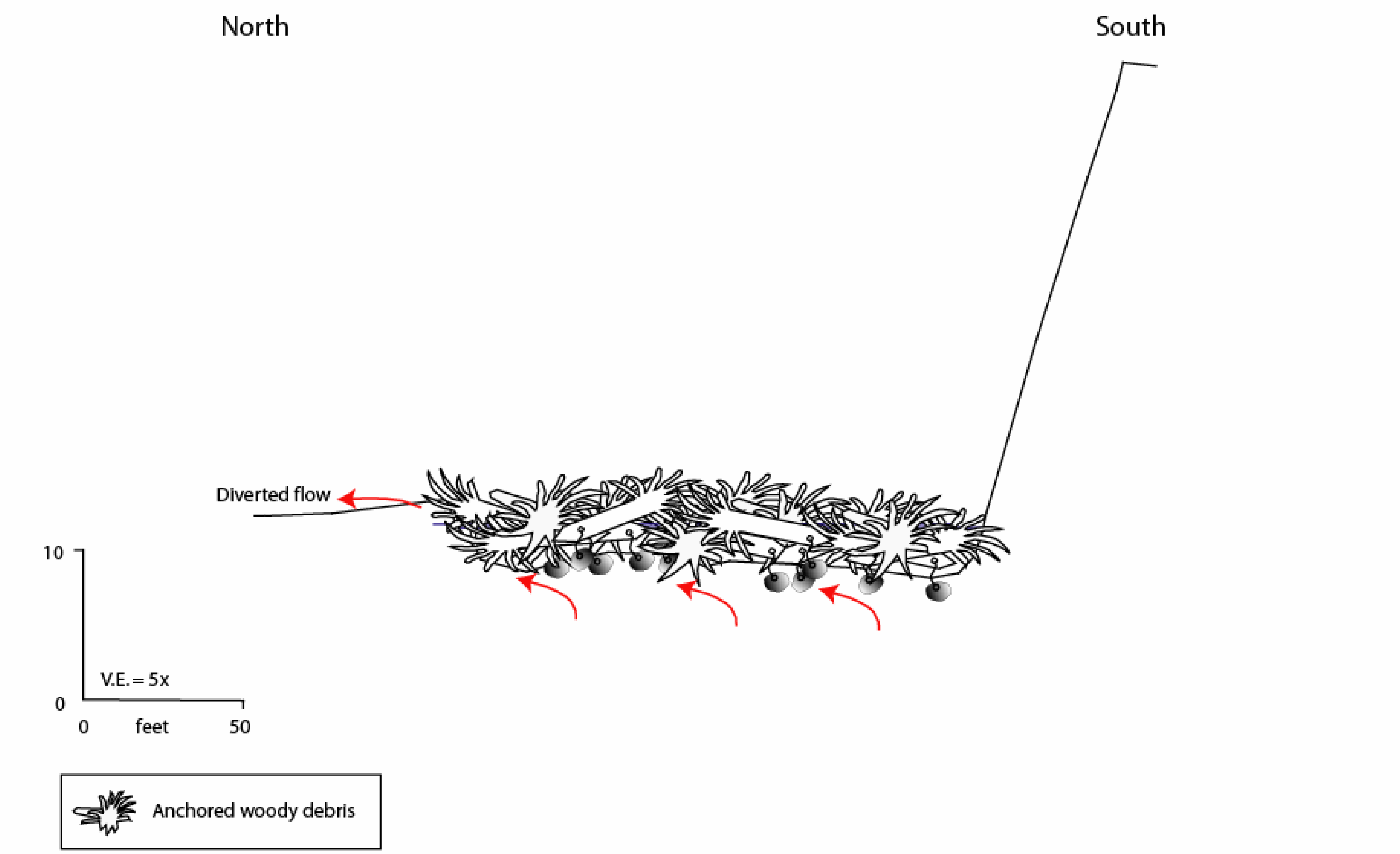
Reach 2 - Flow Diversion (Cross Section)



Note: Woody debris not shown to scale

Flow Diversion Option

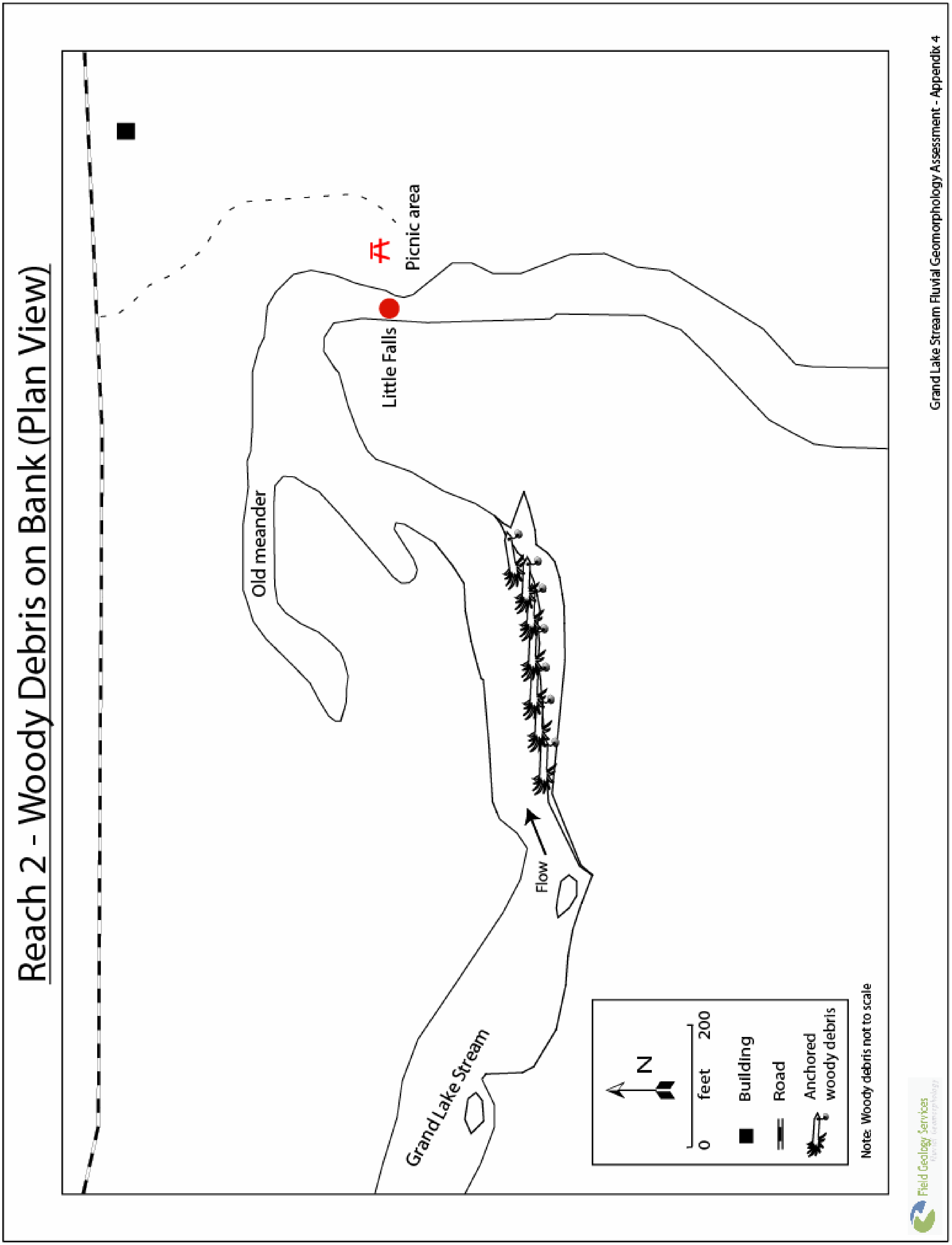
Pros:

- Creates pool habitat
- Better particle size segregation
- Move flow away from high eroding bank
- Restore natural flow patterns

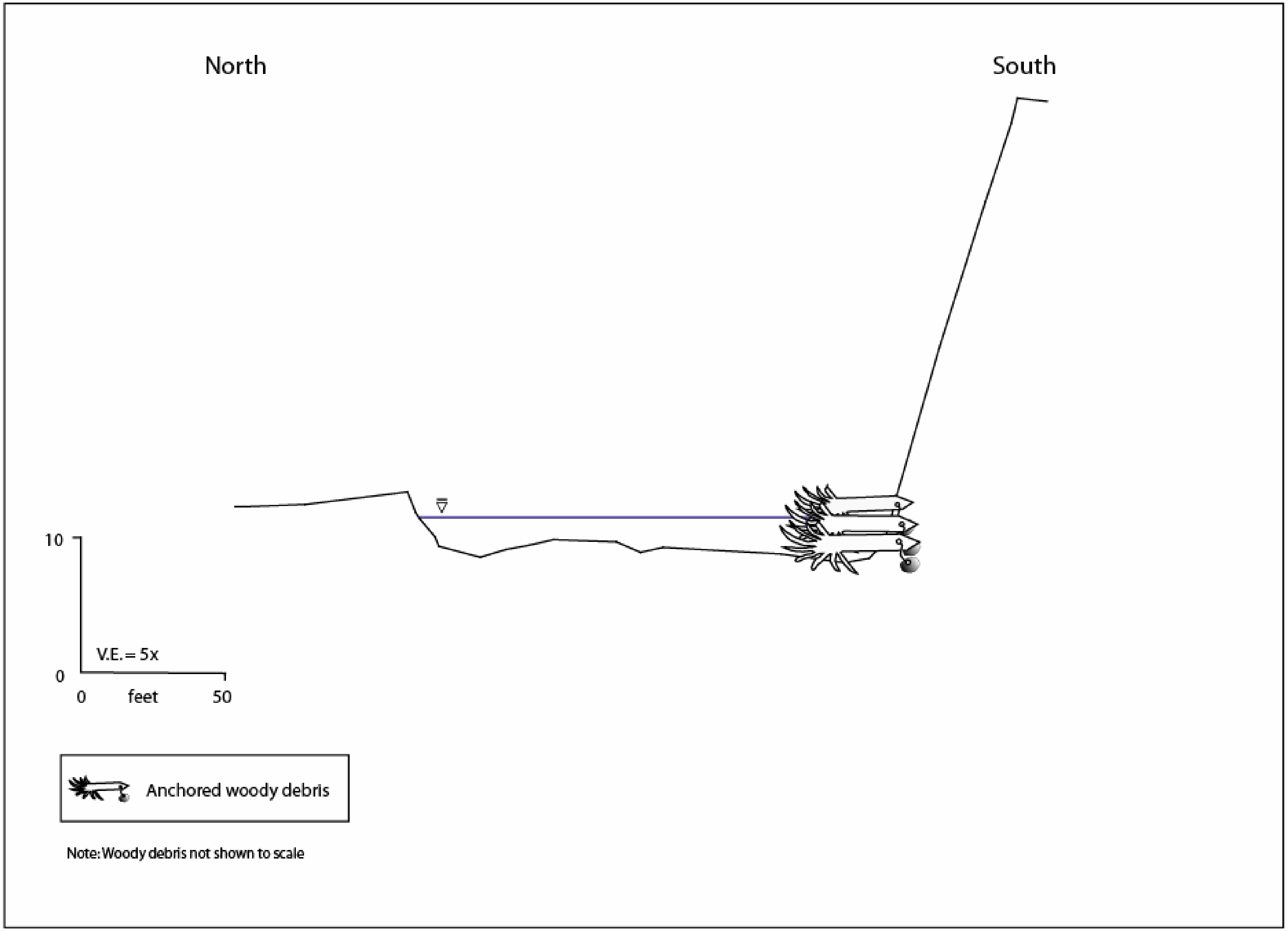
Cons:

- Unintended consequences possible
- Disturbance of channel bed installing log jam
- Financial cost

Field Geology Services
Fluvial Geomorphology


Reach 2 - Woody Debris on Bank (Plan View)
Picnic area
Little Falls
Old meander
Flow
Grand Lake Stream
N
0 feet 200
Building
Road
Anchored woody debris
Note: Woody debris not to scale
Field Geology Services
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4

Reach 2 - Woody Debris on Bank (Cross Section)



Note: Woody debris not shown to scale

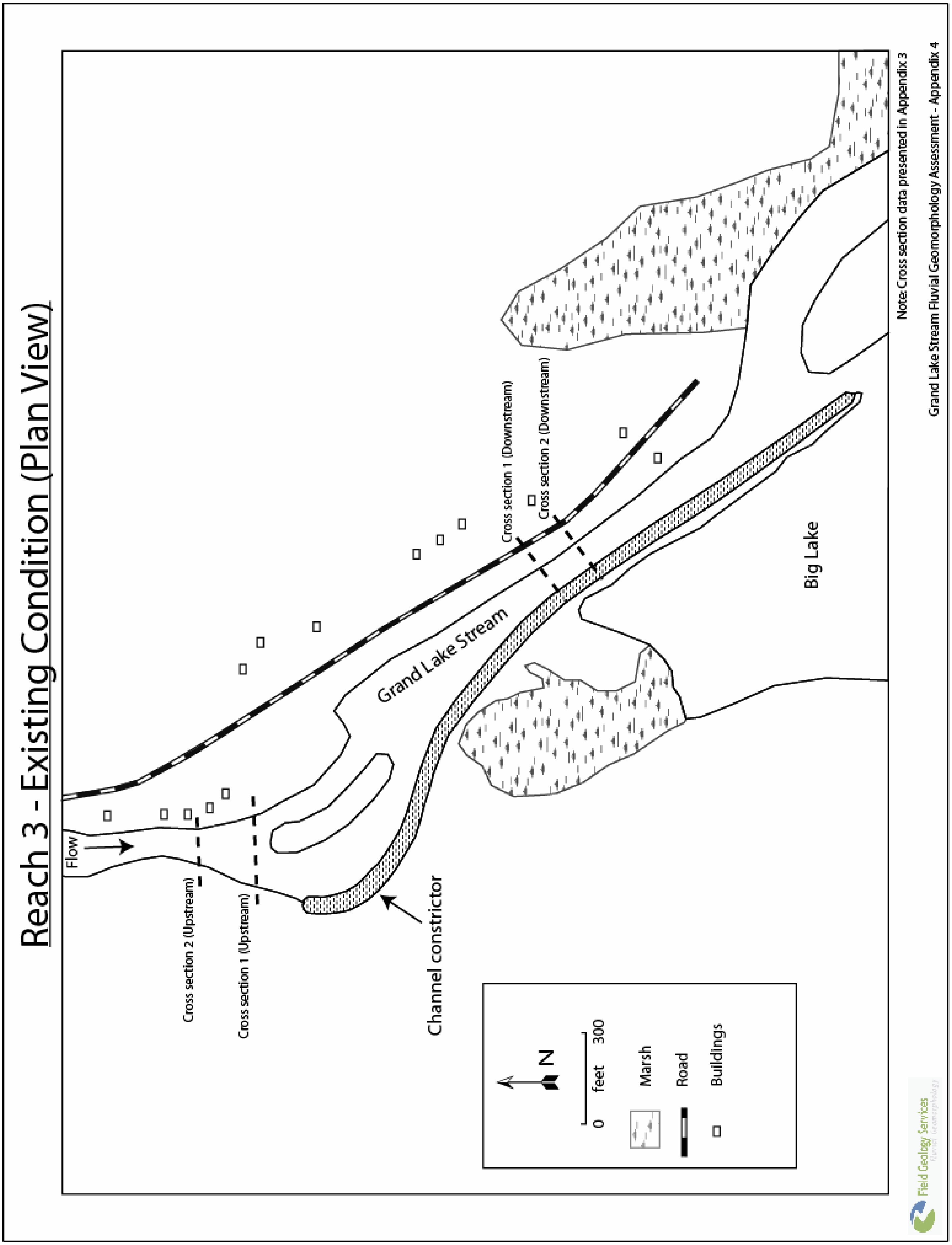
Woody Debris on Bank Option

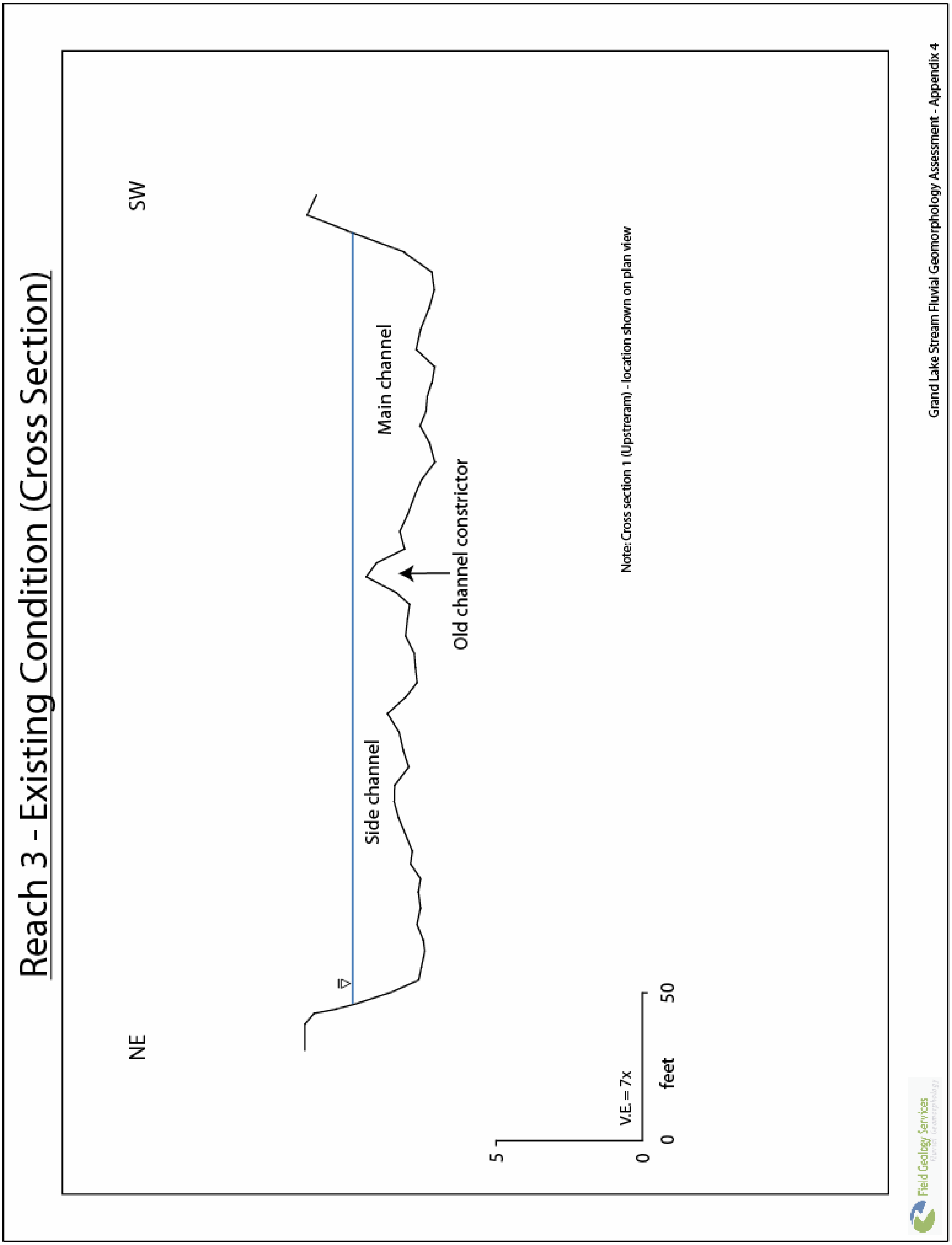
Pros:

- Creates cover habitat
- Minimal short term impact on channel
- Provide bank stability
- Minor channel narrowing
- Mimics natural debris jams

Cons:

- No pool habitat created
- Difficulty anchoring debris to bank
- Erosive pressures remain
- Financial cost


Reach 3 - Existing Condition (Plan View)
Flow
Cross section 2 (Upstream)
Cross section 1 (Upstream)
Channel constrictor
Grand Lake Stream
Cross section 1 (Downstream)
Cross section 2 (Downstream)
Big Lake
N
0 feet 300
Marsh
Road
Buildings
Note: Cross section data presented in Appendix 3
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services


Reach 3 - Existing Condition (Cross Section)
NE
SW
Side channel
Main channel
Old channel constrictor
Note: Cross section 1 (Upstreram) - location shown on plan view
V.E = 7x
5
0
0
feet
50
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services

Do Nothing Option

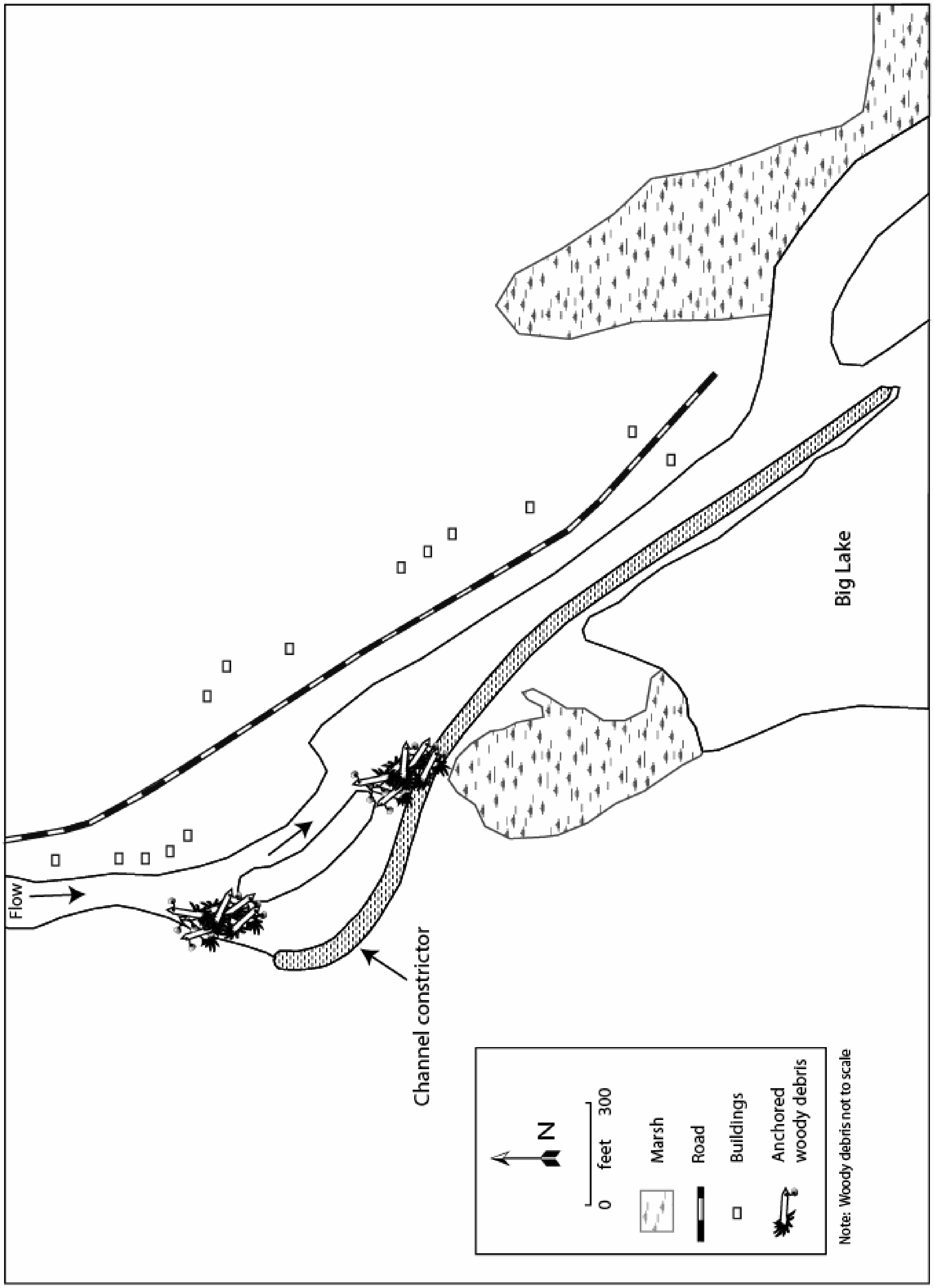
Pros:

- No investment
- No short term construction impacts

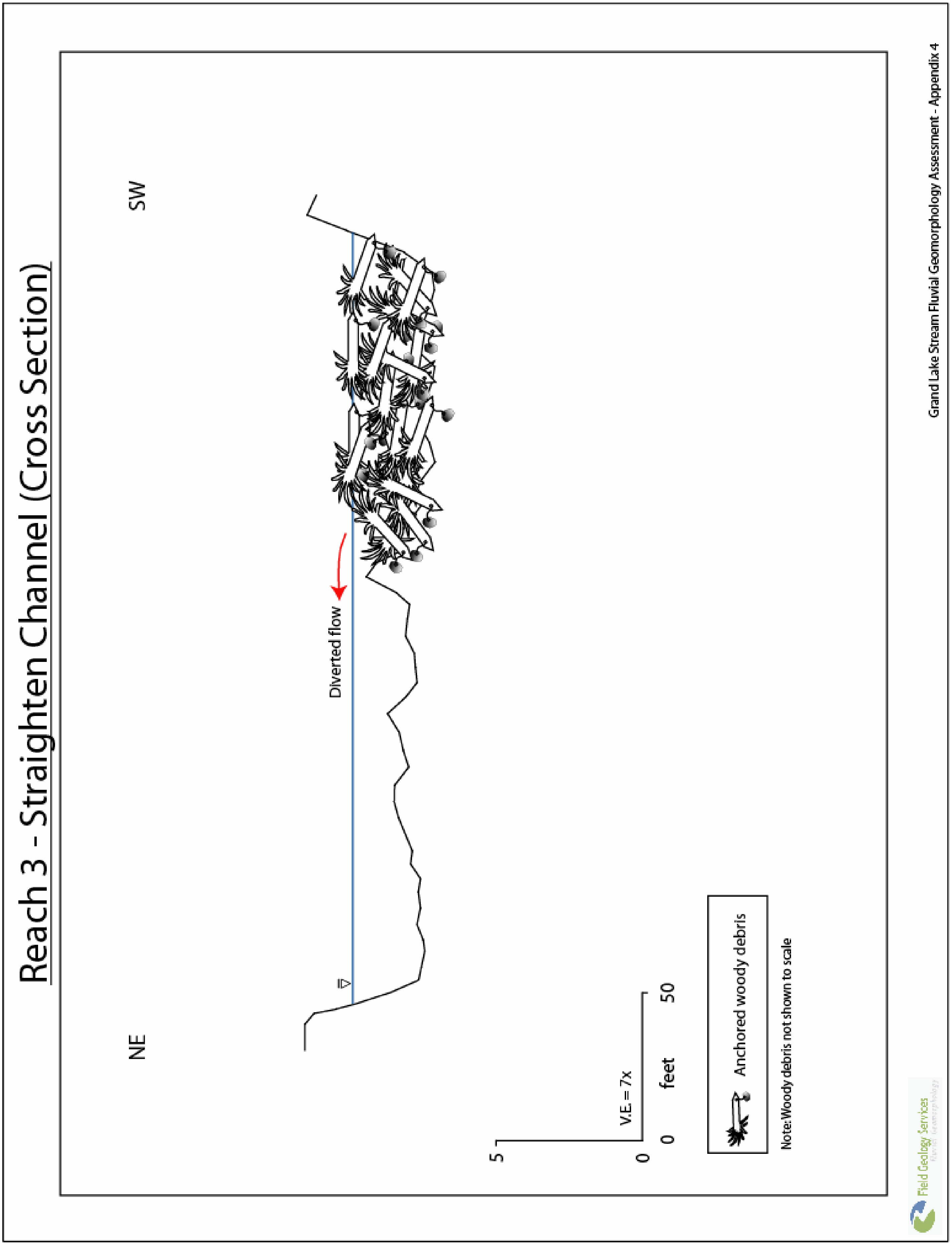
Cons:

- Infilling of channel continues
- No habitat improvement

Reach 3 - Straighten Channel (Plan View)



Field Geology Services


Reach 3 - Straighten Channel (Cross Section)
NE
SW
Diverted flow
V.E. = 7x
5
0
0
feet
50
Anchored woody debris
Note: Woody debris not shown to scale
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services

Straighten Channel Option

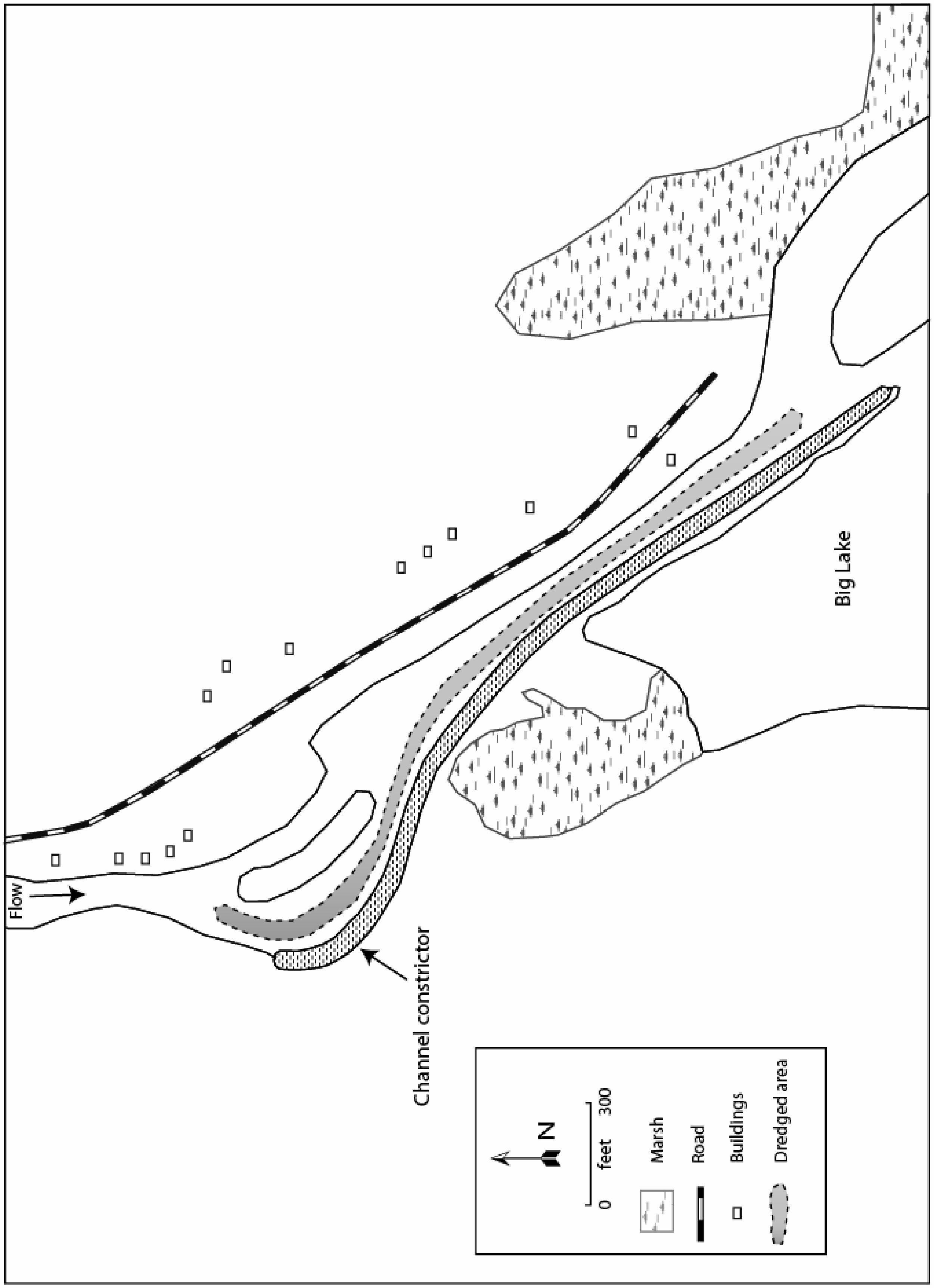
Pros:

- Short term increase in channel depth
- Cover habitat by debris jams blocking main channel
- Transport fine sediments to lake

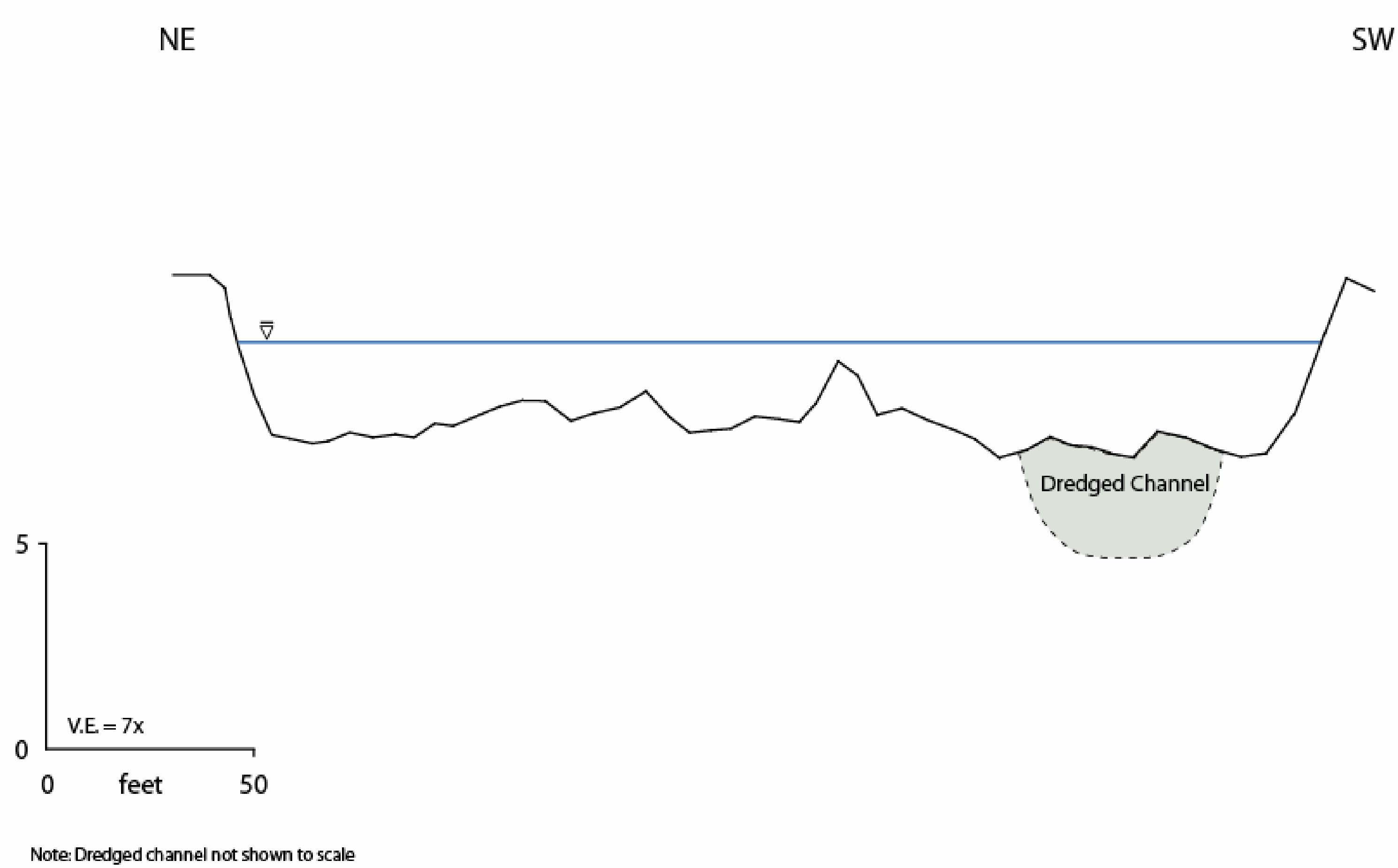
Cons:

- Lose depth in current side channel
- Environmental impacts to Big Lake
- Disturbance in channel
- Financial cost

Reach 3 - Dredge Channel (Plan View)



Reach 3 - Dredge Channel (Cross Section)

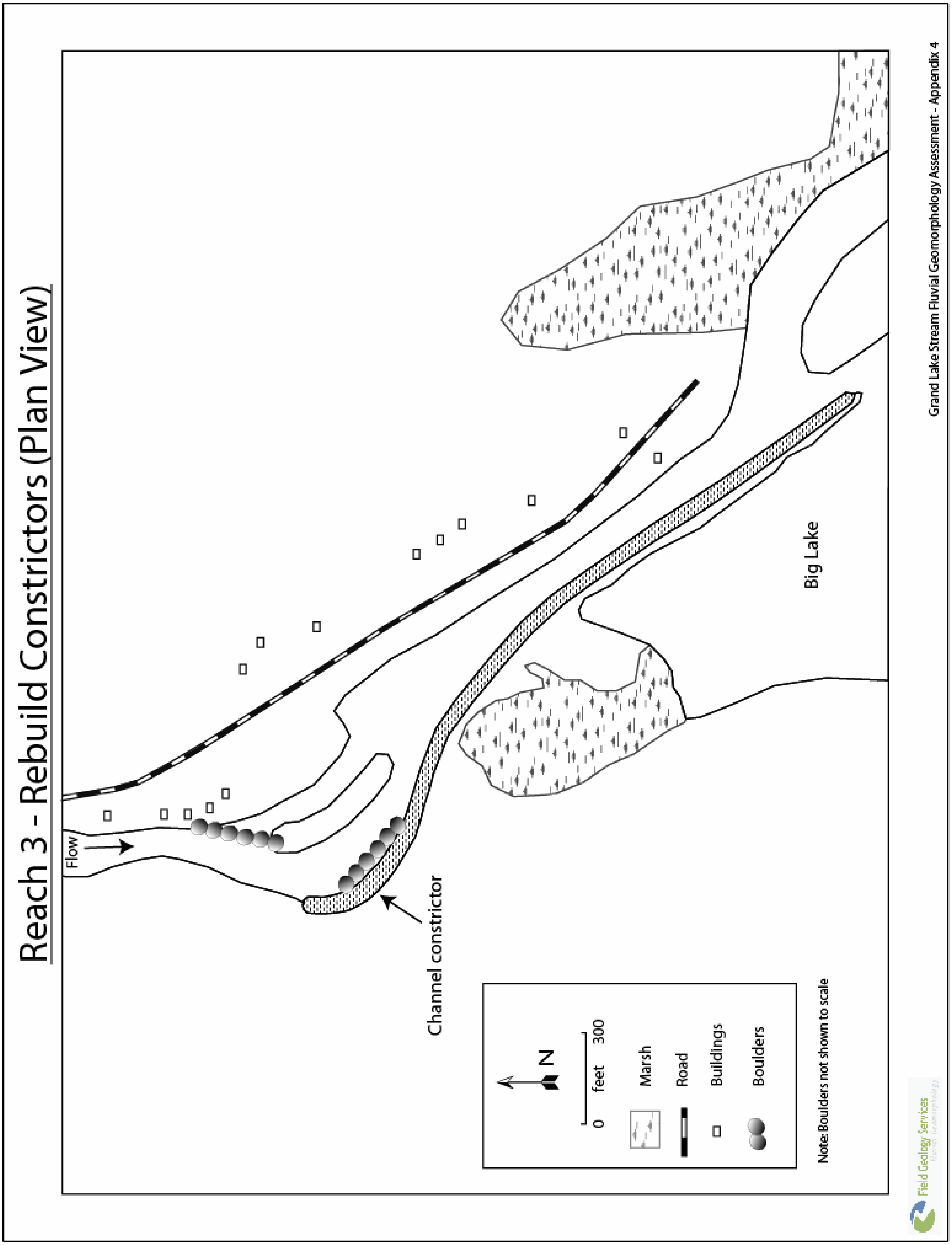


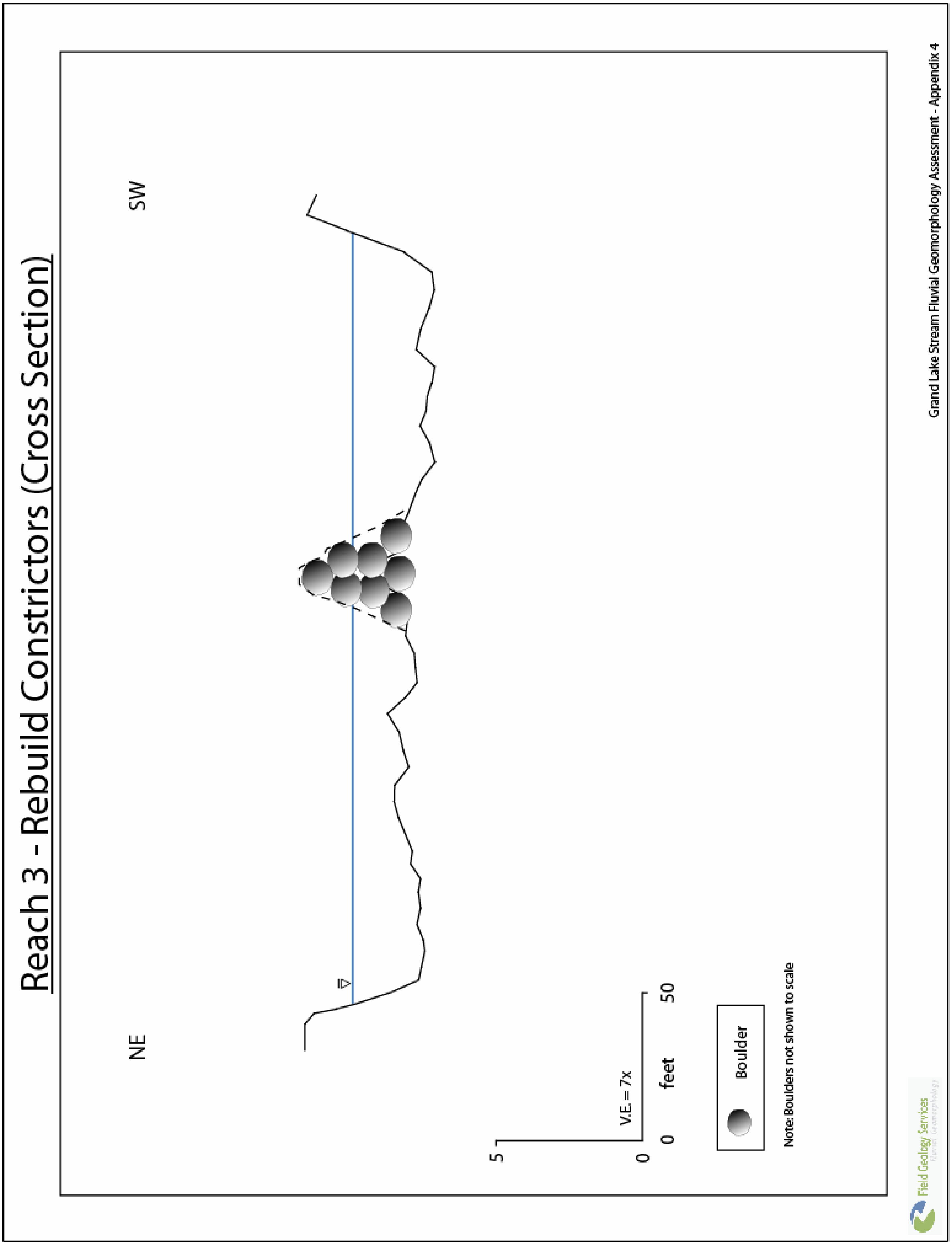
Dredge Channel Option

Pros:
- Creates pool habitat
- Provides water depth for boats

Cons:
- Short term benefits before fills in again
- Disturbance of channel bed
- Financial cost

Field Geology Services
Fluvial Geomorphology


Reach 3 - Rebuild Constrictors (Plan View)
Flow
Channel constrictor
Big Lake
N
0 feet 300
Marsh
Road
Buildings
Boulders
Note: Boulders not shown to scale
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services


Reach 3 - Rebuild Constrictors (Cross Section)
NE
SW
5
0
V.E. = 7x
0
feet
50
Boulder
Note: Boulders not shown to scale
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services

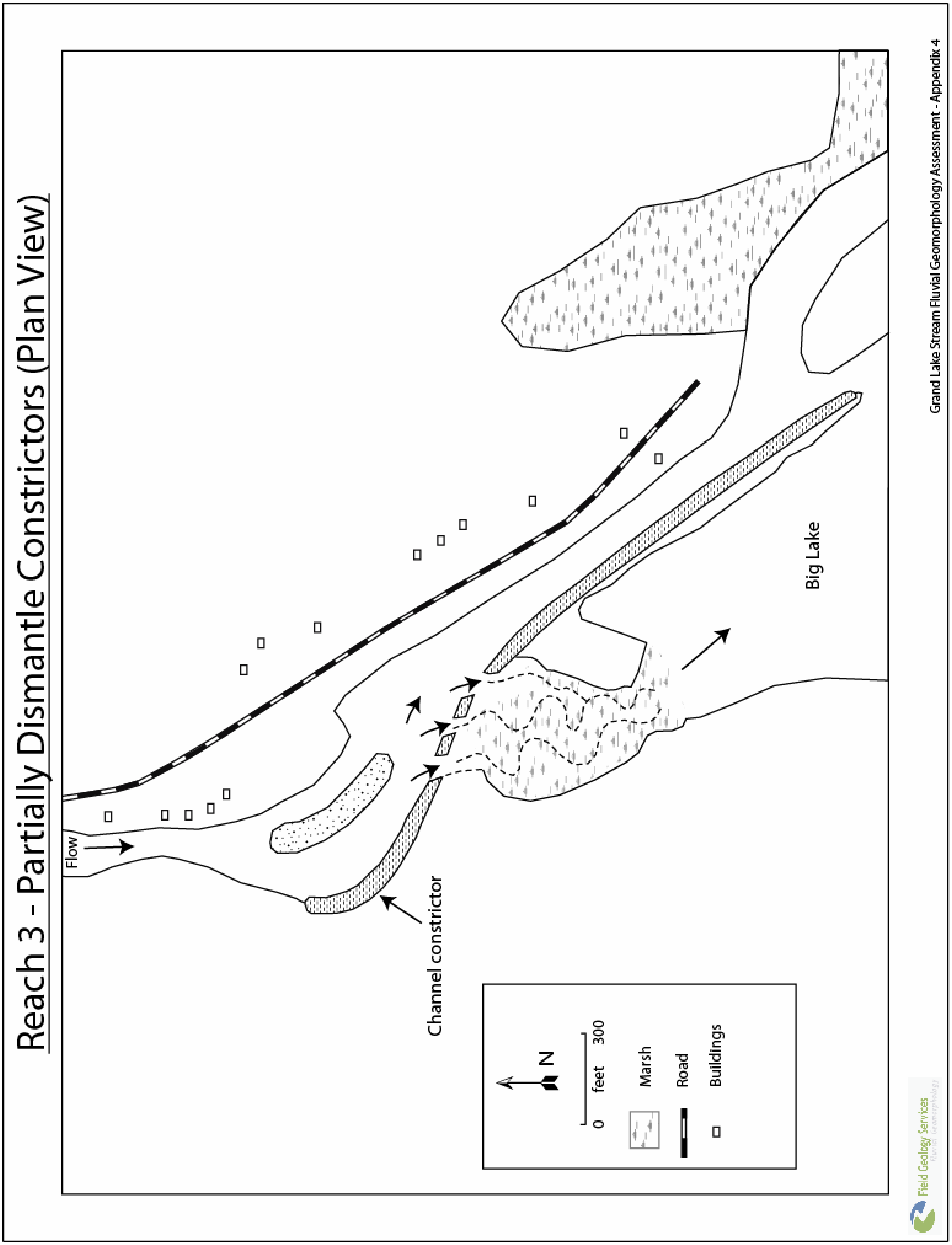
Rebuild Constrictors Option

Pros:

- Improve water depths
- More sustainable than dredging
- Restore historical structures

Cons:

- Environmental impacts to Big Lake
- Disturbance of channel bed
- Periodic maintenance required
- Financial cost


Reach 3 - Partially Dismantle Constrictors (Plan View)
Flow
Channel constrictor
Big Lake
N
0 feet 300
Marsh
Road
Buildings
Grand Lake Stream Fluvial Geomorphology Assessment - Appendix 4
Field Geology Services

Partially Dismantle Constrictors Option

Pros:

- Improve marsh habitat
- Decrease sediment inputs to lake
- Restore natural flow patterns

Cons:

- Channel becomes shallower
- Disturbance of channel bed
- Financial cost